GUIDELINES FOR DRINKING-WATER QUALITY

Vol. 3. Drinking-water quality control in small-community supplies

WORLD HEALTH ORGANIZATION
The World Health Organization is a specialized agency of the United Nations with primary responsibility for international health matters and public health. Through this organization, which was created in 1948, the health professions of some 165 countries exchange their knowledge and experience with the aim of making possible the attainment by all citizens of the world by the year 2000 of a level of health that will permit them to lead a socially and economically productive life.

By means of direct technical cooperation with its Member States, and by stimulating such cooperation among them, WHO promotes the development of comprehensive health services, the prevention and control of diseases, the improvement of environmental conditions, the development of health manpower, the coordination and development of biomedical and health services research, and the planning and implementation of health programmes.

These broad fields of endeavour encompass a wide variety of activities, such as developing systems of primary health care that reach the whole population of Member countries; promoting the health of mothers and children; combating malnutrition; controlling malaria and other communicable diseases including tuberculosis and leprosy; having achieved the eradication of smallpox, promoting mass immunization against a number of other preventable diseases; improving mental health; providing safe water supplies; and training health personnel of all categories.

Progress towards better health throughout the world also demands international cooperation in such matters as establishing international standards for biological substances, pesticides and pharmaceuticals; formulating environmental health criteria; recommending international nonproprietary names for drugs; administering the International Health Regulations; revising the International Classification of Diseases, Injuries, and Causes of Death; and collecting and disseminating health statistical information.

Further information on many aspects of WHO's work is presented in the Organization's publications.
GUIDELINES FOR DRINKING-WATER QUALITY

Volume 3

Drinking-water Quality Control in Small-community Supplies

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</tbody>
</table>
PREFACE

The Guidelines for drinking-water quality are intended to supersede both the European standards for drinking-water\textsuperscript{a} and the International standards for drinking-water,\textsuperscript{b} published in 1970 and 1971, respectively. Volume 1 of the guidelines contains guideline values for various constituents of drinking-water, while Volume 2 contains the criteria monographs that were prepared for each substance or contaminant and on which the guideline values are based.

The present volume deals specifically with drinking-water supplies for small communities, and particularly those in rural areas, with the main emphasis on the microbiological quality of such supplies. It contains information on sanitary inspections, the collection of water samples, simple methods for bacteriological analysis, and methods for determining residual chlorine, suitable for use in rural areas, which take account of the difficulties likely to be faced in the field. It also covers the remedial and preventive measures necessary if water quality is to be maintained, and the community participation which is essential in combating waterborne enteric disease. Conditions will obviously vary from country to country as a result of differences in economic, geographical, cultural and social conditions, but it should be possible for the methods described here to be adapted accordingly. Selected guideline values for drinking-water quality relevant to small community supplies are also given. Like those contained in Volume 1, these are not standards in themselves, but should be carefully considered in the context of the national or local situation when standards or regulations designed to safeguard drinking-water supplies are established. The long-term goal should be the attainment of these guideline values.

It is hoped that the present volume will be useful to all those concerned with drinking-water quality in the rural areas of developing countries, including not only laboratory staff, field workers in surveillance programmes, and those engaged in carrying out remedial measures for safeguarding drinking-water quality, but also administrators and other officials responsible for drawing up or improving national drinking-water quality-control programmes. It is also hoped that it will contribute towards the achievement of the national targets established under the International Drinking Water Supply and Sanitation Decade.

\* \* \*

\textsuperscript{a} European standards for drinking-water, 2nd ed Geneva, World Health Organization, 1970
\textsuperscript{b} International standards for drinking-water, 3rd ed Geneva, World Health Organization, 1971
The preparation of this volume was begun at an Interregional Meeting on Drinking-Water Quality Surveillance for Rural Community Supplies, held in Bangkok on 29 November–3 December 1982, when a detailed outline was agreed. The final version is the outcome of the work of a number of contributors and reviewers whose names are given in Annex 1; their assistance is greatly appreciated. Financial support was provided by the Danish International Development Agency (DANIDA) and by the United Nations Environment Programme, and their contributions are gratefully acknowledged.
1. WATER QUALITY

1.1 Application of guideline values

Guideline values for drinking-water quality are given in Volume 1 of the *Guidelines for drinking-water quality*, which also explains how these values are to be interpreted. A guideline value represents the level (a concentration or a number) of a constituent that ensures an aesthetically pleasing water and does not result in any significant risk to the health of the consumer. The quality of water defined by the guideline values is such that it is suitable for human consumption and for all usual domestic purposes, including personal hygiene. When a guideline value is exceeded the cause should be investigated with a view to taking corrective measures. The amount by which, and the duration for which, any guideline value can be exceeded without affecting public health will depend on the specific substance or characteristic involved.

In developing national drinking-water standards based on the guidelines, it will be necessary to take account of a variety of local geographical, socioeconomic, dietary and industrial conditions. This may lead to the formulation of national standards that differ appreciably from the guideline values. In the case of small-community supplies, particularly in developing countries, the parameters used in assessing and measuring the quality of water intended for public supply must necessarily be limited in number. Similarly, the guideline values given have often to be considered as long-term goals rather than rigid standards that have to be complied with at all times and in all supply systems.

Although any national or regional health authority will make its own choice of parameters and set its own standards, the present guidelines require that those selected should cover the most essential aspects of drinking-water quality. Bearing in mind that emphasis is placed first and foremost on the microbiological safety of drinking-water supplies, only a very limited number of physicochemical parameters are considered to be of general significance for small-community supplies. Wherever chlorine disinfection is applied, the residual chlorine level is considered the most convenient and meaningful parameter to be monitored.

In addition to the presence of high levels of a contaminant, any non-seasonal or sudden changes in level may be indicative of acute pollution of the water source. Immediate sanitary inspection and microbiological, physical or chemical analysis would be the first steps towards determining the necessary remedial measures, which are described in Chapter 7.

1.2 Microbiological aspects

Ideally, drinking-water should not contain any microorganisms known to be pathogenic. It should also be free from bacteria indicative of excremental pollution. To ensure that a supply of drinking-water satisfies these guidelines, it is important that samples should be examined regularly for indicators of faecal pollution. The primary bacterial indicator recommended for this purpose is the coliform group of organisms as a whole. Although as a group they are not exclusively of faecal origin, they are universally present in large numbers in the faeces of man and other warm-blooded animals, and thus can be detected even after considerable dilution. The detection of faecal (thermotolerant) coliform organisms, in particular *Escherichia coli*, provides definite evidence of faecal pollution.

Guideline values ensuring bacteriologically safe supplies of drinking-water are provided in Volume 1 of the guidelines. Although developed for large water-supply systems, the values for piped and unpiped water supplies are also applicable to small-community supplies and are therefore reproduced in Table 1. Background information on the significance and choice of indicator organisms as well as the selection of analytical methods is given in Chapter 5.

It has been demonstrated that chlorination can produce virus-free water from faecally polluted source waters when the concentration of free residual chlorine is at least 0.5 mg/litre for a minimum contact period of 30 minutes at a pH below 8.0 and a turbidity of 1 nephelometric turbidity unit (NTU) or less. It is also desirable to maintain a free residual chlorine level of

---

**Table 1. Guideline values for bacteriological quality**

<table>
<thead>
<tr>
<th>Organism</th>
<th>Unit</th>
<th>Guideline value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Piped water supplies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.1 Treated water entering the distribution system faecal coliforms</td>
<td>number/100 ml</td>
<td>0</td>
<td>turbidity &lt; 1 NTU, for disinfection with chlorine, pH preferably &lt; 8.0, free chlorine residual 0.2–0.5 mg/litre following (minimum) contact time of 30 minutes</td>
</tr>
<tr>
<td>faecal coliforms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>A.2 Untreated water entering the distribution system</strong> faecal coliforms</td>
<td>number/100 ml</td>
<td>0</td>
<td>in an occasional sample but not in consecutive samples</td>
</tr>
<tr>
<td>faecal coliforms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>3</td>
<td>in an occasional sample but not in consecutive samples</td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>A.3 Water in the distribution system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>faecal coliforms</td>
<td>number/100 ml</td>
<td>0</td>
<td>in an occasional sample but not in consecutive samples</td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>B. Unpiped water supplies</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>faecal coliforms</td>
<td>number/100 ml</td>
<td>0</td>
<td>should not occur repeatedly; if occurrence is frequent and sanitary protection cannot be improved, an alternative source must be found if possible</td>
</tr>
<tr>
<td>coliform organisms</td>
<td>number/100 ml</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

0.2–0.5 mg/litre in the distribution system to reduce the risk of microbial regrowth. The detection of chlorine in this concentration range provides an indication of the absence of post-treatment contamination.

There should be an immediate increase in disinfectant application to achieve a free chlorine residual of 0.2–0.5 mg/litre in all portions of the distribution system when total coliform densities of more than 3 organisms per 100 ml are found in successive samples or when 1 or more faecal coliforms per 100 ml are detected.

Chlorine is pre-eminent as a disinfectant because of its ready availability and cheapness, as well as the ease with which it can be used, controlled and measured in water. The most common methods and techniques for the determination of residual chlorine are described in Chapter 6.

1.3 Biological aspects

It is not easy to give guidelines on biological hazards that are generally applicable. This is particularly true in respect of parasitic protozoa and helminths, and the application of any guidelines and procedures proposed must be governed by epidemiological considerations in at least two respects: (1) many parasites have a complex geographical distribution and it may be unnecessary to take precautions against those not occurring locally; and (2) the majority of waterborne parasites are also transmissible by other routes, such as food and direct faecal-oral spread, and these routes should also be considered.

1.3.1 Protozoa

Species of protozoa known to have been transmitted by the ingestion of contaminated drinking-water include Entamoeba histolytica (cause of amoebiasis), Giardia spp. and, rarely, Balantidium coli. These organisms can be introduced into a water supply through human or, in some instances, animal faecal contamination.

Coliform organisms do not appear to be a good indicator for Giardia or E. histolytica in treated water because of the greater resistance of these protozoans to inactivation by disinfection. In non-disinfected water, the presence of indicator bacteria could suggest the presence of pathogenic protozoa. Since there is no good indicator for the presence or absence of pathogenic protozoa, drinking-water sources not subject to faecal contamination should be used where possible.

1.3.2 Helminths

The infective stages of many parasitic roundworms and flatworms can be transmitted to man through drinking-water. A single mature larva or fertilized egg can cause infection and it is clear that such infective stages should be absent from drinking-water. However, the water route is relatively
unimportant except in the case of *Dracunculus medinensis* (the guinea-worm) and the human schistosomes, which are hazards that are primarily encountered in unpiped water supplies. While there are methods for detecting these parasites, they are quite unsuited for routine monitoring.

*Dracunculus* may be a cause of severe morbidity in rural populations and is transmitted by freshwater copepods, such as *Cyclops*, which represent an obligatory intermediate stage. Larvae reach the copepods when a blister on the limb of an infected person bursts and the larvae are washed into open wells and ponds. The parasites infect man when the copepod is ingested. In order to determine whether a risk of infection exists, copepods may be collected in plankton nets and examined for parasitic larvae under the microscope; the prevalence of the disease in man should also be investigated. Neither of these measures is suitable for routine use.

### 1.4 Chemical and physical aspects

Although in the rural areas of developing countries the great majority of water-quality problems are related to bacteriological or other biological contamination, a significant number of very serious problems may occur as a result of chemical contamination of water resources. Such contamination may arise from certain industries, such as mining and smelting, or from agricultural practices and malpractices (e.g., the use and misuse of nitrates as fertilizers), or from natural sources (e.g., iron, fluoride). In order to establish whether such problems exist, a selected number of physicochemical parameters may need to be measured. However, particularly in the case of rural water supplies in developing countries, it could be both very costly and physically impracticable to cover a large number of parameters, and in most cases, testing may initially have to be limited primarily to sanitary inspection and bacteriological analysis.

If there are chemical constituents of local significance, the levels should be measured and the results evaluated in the light of the guideline values and other recommendations made in Volume 1.a In other areas, although no general recommendations or universally applicable selection of parameters can be given, there are a few indicative parameters of practical importance, which can provide useful guidance in assessing water quality. Guideline values for turbidity, colour, and taste and odour are recommended for use in the surveillance of small-community supplies.

### 1.4.1 Turbidity

High levels of turbidity can protect microorganisms from the effects of disinfection, stimulate the growth of bacteria and exert a significant chlorine demand. In all processes in which disinfection is practised, therefore, the

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*a Guidelines for drinking-water quality Vol 1, op cit*
1. WATER QUALITY

turbidity must always be low, preferably below 1 NTU for effective disinfection. The recommended guideline value is 5 nephelometric turbidity units (NTU) or 5 Jackson turbidity units (JTU), but levels should preferably be less than 1 NTU when disinfection is practised. Turbidity in excess of 5 NTU (5 JTU) may be noticeable and consequently objectionable to consumers.

1.4.2 Colour

Colour in drinking-water may be due to the presence of coloured organic matter, e.g., humic substances, metals such as iron and manganese, or highly coloured industrial wastes. Experience has shown that consumers may turn to alternative, perhaps unsafe, sources, when their water displays aesthetically displeasing levels of colour. It is desirable, therefore, that drinking-water should be colourless.

The guideline value is 15 true colour units (TCU). Levels of colour above 15 TCU can be detected in a glass of water by most people.

1.4.3 Taste and odour

Water odour is due mainly to the presence of organic substances. Some odours are indicative of increased biological activity, others may originate from industrial pollution. Sanitary surveys should always include investigations of possible or existing sources of odour, and attempts should always be made to correct an odour problem.

The combined perception of substances detected by the senses of taste and smell is often called "taste". "Taste" problems in drinking-water supplies represent the largest single class of consumer complaints. Generally, the taste buds in the oral cavity specifically detect inorganic compounds of metals such as magnesium, calcium, sodium, copper, iron, and zinc.

Changes in the normal taste of a public water supply may signal changes in the quality of the raw water source or deficiencies in the treatment process.

As water should be free of objectionable taste and odour for the large majority of the consumers, the guideline criterion is "not offensive to most of the consumers".
2. PLANNING FOR WATER-QUALITY SURVEILLANCE AND CONTROL

2.1 Organizational framework

The precise meaning of "surveillance" in relation to the control of drinking-water quality is not always clear. As used here, it means the keeping of a careful watch at all times, from the public health point of view, over the safety and acceptability of drinking-water supplies. Surveillance requires a continuous and systematic programme of surveys, carried out at different points of the water distribution system. A surveillance programme aimed at ensuring a consistently acceptable level of drinking-water quality, if it is to be fully effective, may also require legislation supported by regulatory standards and codes of practice. However, in developing countries—many of which lack adequate community water supplies—and in particular in the rural areas and urban squatter settlements of such countries, surveillance should take into account local conditions and be adapted to the levels of economic and manpower development.

The organizational arrangements aimed at ensuring compliance with the requirements of legislation, standards, or codes of practice for drinking-water quality must provide for surveillance to be shared between the water-supply agency and a separate, and preferably independent, surveillance agency. The former is responsible at all times for the quality and safety of the water it produces. In this publication, the routine testing and monitoring carried out by the water supplier will be called water-quality control testing; this should not be confused with the separate checking and testing carried out by the surveillance agency. Both water-quality control testing and testing by the surveillance agency should be applied to all the types of water available to the community, e.g., piped or unpiped, treated or untreated supplies, derived from any suitable source, such as rivers, ponds, wells, roof run-off, etc.

The surveillance agency should preferably be established with national support and operate at central, provincial (regional), and local levels, usually through the health authority. It should be concerned with the public health aspects of drinking-water supplies, and have overall responsibility for ensuring that all such supplies under its jurisdiction are free from health hazards. To this end, it should carry out periodic sanitary inspections and analyses of water samples to determine whether the suppliers are fulfilling their responsibilities.

Because the water-supply agency and the surveillance agency have different and sometimes conflicting interests, it is important that the latter is separate and
independently controlled. Nevertheless, the roles of the two agencies are essentially complementary since their surveillance activities, although independent, in combination result in the proper control of drinking-water quality. Some important aspects of the surveillance programme are as follows:

(a) The agency should have the sole responsibility within the health authority for providing surveillance services to protect the public from waterborne diseases and other hazards associated with the water supply.

(b) Water-quality surveillance should be integrated with other environmental health measures, especially sanitation.

(c) Surveillance requires specialized knowledge and the agency should thus include personnel specially trained in matters such as sanitary engineering, community health, epidemiology, chemistry, biology, etc.; additional support should be provided by the medical profession, particularly during an outbreak of enteric disease.

(d) Health authorities should possess centralized laboratories and other services which can be advantageously used for the conduct of programmes of surveillance of water supplies.

(e) Periodic reports to the government regarding the public health situation of the country’s water supplies are essential.

If the operational standards of water-supply agencies are high, the duties of the surveillance agency can be reduced to a minimum. In these circumstances, the surveillance agency, while still retaining the ultimate responsibility for ensuring the safety of all public water supplies, should be able to give greater attention to the supply systems having water of the poorest quality.

Both the programme and the level of surveillance should be adapted to local conditions and the economic resources of the country and take into account the following:

- the type of water-supply system (size, type of source, water quality, etc.);
- the equipment used and available;
- local employment practices and level of training of personnel;
- the socioeconomic level of the community served by the water-supply system;
- community participation;
- geographical and climatological conditions;
- the local communication and transportation infrastructure.

Although the main objective of a surveillance and control programme is to ensure a safe and adequate supply of drinking-water, certain other subsidiary objectives can be defined, for example:

(a) determination of trends in drinking-water quality over time;
(b) provision of information to public health authorities for general public health protection purposes;
(c) identification of sources of contamination;
(d) assessment of the performance of water-treatment plants; if necessary, appropriate modifications may be suggested;
(e) evaluation of water-supply systems with a view to improving them.
Because of the limited resources available, particularly in developing countries, it may be advisable to start with a fairly basic surveillance programme, and then to improve on it in stages. In planning for the future the aim should be to provide increasing levels of surveillance activity, ultimately reaching an advanced level (see below).

For practical purposes, two levels of surveillance can be identified and characterized as follows:

*Initial level*: irregular surveillance, or a basic programme that is severely limited in scope and effectiveness;

*Advanced level*: all surveillance and control elements fully operational.

The principal activities at these two levels of surveillance are summarized in Table 2.

**Table 2. Summary of principal activities for initial and advanced levels of surveillance**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Initial</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>laws, regulations and policies</td>
<td>basic</td>
<td>complete</td>
</tr>
<tr>
<td>enforcement</td>
<td>basic</td>
<td>complete</td>
</tr>
<tr>
<td>drinking-water standards</td>
<td>bacterial and some</td>
<td>numerous parameters as defined in guidelines published by WHO, or equivalent</td>
</tr>
<tr>
<td></td>
<td>physicochemical parameters</td>
<td></td>
</tr>
<tr>
<td>technical assistance</td>
<td>limited</td>
<td>active</td>
</tr>
<tr>
<td>training of staff</td>
<td>on-the-job, plus short courses</td>
<td>as for initial level plus technical institute</td>
</tr>
<tr>
<td>waterworks operators</td>
<td>seminars plus short courses</td>
<td>as for initial level plus technical institute</td>
</tr>
<tr>
<td>sanitary inspections</td>
<td>all urban and some</td>
<td>all urban, many small communities</td>
</tr>
<tr>
<td></td>
<td>small communities</td>
<td></td>
</tr>
<tr>
<td>approval of sources</td>
<td>all urban and some</td>
<td>all urban, many small communities</td>
</tr>
<tr>
<td></td>
<td>small communities</td>
<td></td>
</tr>
<tr>
<td>sampling and monitoring</td>
<td>urban areas</td>
<td>urban areas and special rural situations</td>
</tr>
<tr>
<td>water analysis</td>
<td>bacteria and residual</td>
<td>as given in guidelines published by WHO, or equivalent</td>
</tr>
<tr>
<td></td>
<td>chlorine</td>
<td></td>
</tr>
<tr>
<td>remedial action</td>
<td>as needed</td>
<td>as needed</td>
</tr>
<tr>
<td>laboratories</td>
<td>existing health laborator</td>
<td>as for initial level plus reference laboratory</td>
</tr>
<tr>
<td>design standards or criteria</td>
<td>advisory</td>
<td>those applicable nationally</td>
</tr>
<tr>
<td>control of cross-connections</td>
<td>advisory</td>
<td>active programme</td>
</tr>
<tr>
<td>plumbing code</td>
<td>advisory</td>
<td>codified and enforced</td>
</tr>
<tr>
<td>laboratory support services</td>
<td>basic media and re-</td>
<td>fully equipped laboratories available</td>
</tr>
<tr>
<td></td>
<td>agents available</td>
<td></td>
</tr>
<tr>
<td>standards for materials and additives</td>
<td>advisory</td>
<td>approved listing</td>
</tr>
<tr>
<td>regulations for special water supplies</td>
<td>hospitals, major rail</td>
<td>as for initial level plus other establishments</td>
</tr>
<tr>
<td>institutional</td>
<td>and air terminals</td>
<td></td>
</tr>
<tr>
<td>temporary</td>
<td>none</td>
<td>large camps, markets, fairs, etc</td>
</tr>
</tbody>
</table>
2.2 Assessment of existing situation

Water-supply systems vary greatly in size, ranging from small systems serving individual families, e.g., from a well or a rainwater cistern, to systems serving many consumers. Adequate and safe water supplies may not be available in a large number of villages in the rural areas and in many squatter settlements in urban areas, where the control, operation, and maintenance of water systems is often inadequate. Small-community populations are often at great risk from waterborne diseases, and their water supplies need to be safeguarded, something that can be achieved only through effective surveillance. Information on general health, gathered at central, provincial (regional), and local (or equivalent) levels, will help to define priorities for the surveillance programme within a country. An inventory of the existing and proposed water-supply systems should be prepared at each level and should include details of the water source, size and type of any water-treatment plant, the distribution systems (if any), populations served, etc. The supporting services available, such as transportation and facilities for analysis, also need to be identified. From an analysis of all the information in the inventory, the workload for the surveillance activity can be assessed and the cost of surveillance calculated; this is essential if a realistic programme is to be undertaken. A suggested form for the inventory of water-supply systems is given in Fig. 1.

Fig. 1. Suggested form for inventory of water-supply systems

<table>
<thead>
<tr>
<th>Date of inspection</th>
<th>Day</th>
<th>Month</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>General information</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name of supply</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owned by</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Persons in charge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of persons served</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>—by house connections</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>—by standposts or public hydrants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>—total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Source of water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water collection and treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dug well</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilled well</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infiltration gallery</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface-water intake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple rainwater collection system</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GUIDELINES FOR DRINKING-WATER QUALITY

Fig. 1 (continued)

Rainwater collection system with treatment [ ]
Slow sand filtration [ ]
Coagulation and rapid sand filtration [ ]
Aeration [ ]

Disinfection
Is there any means of disinfection? Yes [ ] No [ ]
Is the system functioning continuously? Yes [ ] No [ ]

Reservoirs
Are there reservoirs in the system? Yes [ ] No [ ]
If yes: how many?

Distribution system
Number of house connections [ ]
Number of standposts or public hydrants [ ]
Total [ ]

Open systems* [ ] Closed systems* [ ]

Schematic diagram of water system from source intake to distribution (rough sketch only).

Laboratory facilities
Nearest laboratory in community [ ] outside community [ ]
If outside community, in which place . . . .
Name of laboratory . . . .
 Owned by . . . .
Distance from community to laboratory (in km) [ ]
Best form of transport between community and laboratory . . . .
Frequency of transportation [ ] days per month [ ] days per week
Fastest transportation time (in hours) [ ]

Surveillance facilities
Nearest personnel for sanitary inspection in community [ ] outside community [ ]
If outside community, in which place . . . .
Distance from community to sanitary inspector's office (in km) [ ]

* For examples of "open" and "closed" systems, see Fig. 3, p. 20, and Fig. 4, p. 21
2.3 Sanitary inspections and water sampling

The planning of sanitary inspections and water-sampling programmes for bacteriological testing depends on the work-load in relation to the number and type of existing and proposed water-supply systems, and the size and type of the control systems used.

Suggested frequencies of inspection and sampling are indicated in Tables 3 and 4; these may be increased as the level of surveillance improves.

<table>
<thead>
<tr>
<th>Source and mode of supply</th>
<th>By community workers</th>
<th>By water-supply agency</th>
<th>By surveillance agency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Groundwater</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>open wells for community supply</td>
<td>12</td>
<td>—</td>
<td>once initially, thereafter as situation demands</td>
</tr>
<tr>
<td>covered dug wells and shallow tube-wells with hand-pumps</td>
<td>4</td>
<td>—</td>
<td>once initially, thereafter as situation demands</td>
</tr>
<tr>
<td>deep tubewells with hand-pumps</td>
<td>4</td>
<td>—</td>
<td>once initially, thereafter as situation demands</td>
</tr>
<tr>
<td>wells and piped supplies</td>
<td>1</td>
<td>1</td>
<td>once initially, thereafter once every 5 years, or as situation demands</td>
</tr>
<tr>
<td>springs and piped supplies</td>
<td>1</td>
<td>1</td>
<td>once initially, thereafter once every 5 years, or as situation demands</td>
</tr>
<tr>
<td><strong>Surface water and rainwater</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>filtered and/or chlorinated and piped supplies:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>population up to 5000</td>
<td>12</td>
<td>2</td>
<td>once initially, thereafter once every 5 years, or as situation demands</td>
</tr>
<tr>
<td>population 5000–20 000</td>
<td>—</td>
<td>24–48</td>
<td>every system once per year</td>
</tr>
<tr>
<td>community rainwater collection systems</td>
<td>1</td>
<td>—</td>
<td>once initially, thereafter as situation demands</td>
</tr>
</tbody>
</table>

2.4 Handling and use of information

2.4.1 Results of water analysis

In the case of water-quality testing carried out by the surveillance agency, the lines of communication normally pass through a regional surveillance agency. Field testing and sampling for microbiological analysis can be carried out by selected local personnel; this saves time and effort but requires the prior training of such personnel. Samples can be transported to a designated
Table 4. Suggested frequency of sampling and analysis of water supplies

<table>
<thead>
<tr>
<th>Source and mode of supply</th>
<th>Bacteriological</th>
<th>Physical/chemical</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>open wells for community supply</td>
<td>Nil*</td>
<td>once initially for community wells</td>
<td>pollution usually expected to occur</td>
</tr>
<tr>
<td>covered dug wells and shallow tubewells with hand-pumps</td>
<td>Nil*</td>
<td>once initially, thereafter as situation demands</td>
<td>situations requiring testing; change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases</td>
</tr>
<tr>
<td>deep tubewells with hand-pumps</td>
<td>once initially, thereafter as situation demands</td>
<td>once initially, thereafter as situation demands</td>
<td>situations requiring testing; change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases</td>
</tr>
<tr>
<td>wells and piped supplies</td>
<td>once initially, thereafter as situation demands</td>
<td>test periodically for residual chlorine if water is chlorinated</td>
<td>situations requiring testing; change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases</td>
</tr>
<tr>
<td>springs and piped supplies</td>
<td>once initially, thereafter as situation demands</td>
<td>test periodically for residual chlorine if water is chlorinated</td>
<td>situations requiring testing; change in environmental conditions, outbreak of waterborne disease, or increase in incidence of waterborne diseases</td>
</tr>
<tr>
<td>Surface water and rainwater</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>filtered and/or chlorinated and piped supplies</td>
<td>once per month</td>
<td>residual chlorine test daily</td>
<td>increase frequency if situation demands</td>
</tr>
<tr>
<td>community rainwater-collection systems</td>
<td>sanitary protection measures, bacteriological testing only if situation demands</td>
<td>not needed</td>
<td>—</td>
</tr>
</tbody>
</table>

* See Table 5 (p. 36) for remedial and preventive measures
laboratory in the region, which should be responsible for handling and communicating the results of the analyses.

Where the regional surveillance agency decides that the results of the water analyses are unsatisfactory (also taking into account the results of sanitary inspections) and that immediate remedial action is required, that decision together with the appropriate instructions must be conveyed (ideally by radio or telegram), both to the surveillance agency and to the responsible water-supply agency at local level. In addition, written confirmation must be sent as soon as possible. In case it may be necessary to exert pressure on the local water-supply agency to deal with any problems relating to the water supply, the water-supply agency at the next highest level should be informed in writing of the situation as soon as possible. Depending on the structure of the water-supply agencies in the country, it is often necessary for the surveillance agency also to inform the highest level water-supply agency; this ensures that records are available for use in future planning. The water-supply agency responsible at the local level should alert local personnel in case further sampling, tests, or other activities are necessary.

As a guide for those carrying out remedial measures, the surveillance agency should provide them with the following:

(a) a report on the situation;
(b) information on the date, time and place at which the contamination or other problem occurred;
(c) suggestions as to the remedial measures required.

The remedial measures may consist of "high-level" disinfection of the water supply, i.e., the provision of a gross excess of chlorine or other disinfectant, and/or flushing of the distribution systems, where appropriate, and redisinfection.

In addition, the surveillance agency should also immediately alert the population to the situation and advise them to boil all their drinking-water.

Although less urgent, it is also very important that, whenever feasible:
- the water supply should be resampled for microbiological examination as soon as possible;
- residual chlorine levels should be checked at appropriate points;
- a full sanitary inspection should be made;
- the cause or source of the problem should be identified and the situation rectified;
- the water-supply agency should be informed of the action taken.

Further information on preventive and remedial measures is provided in Chapter 7.

2.4.2 Results of sanitary inspections

If the results of sanitary inspections are unsatisfactory, action should be taken in a manner similar to that previously described for water-quality analysis. Certain of these actions are carried out by the surveillance agency,
and others by the water-supply agency. Ideally, the remedial measures applied to the water-supply system should be the responsibility of the water-supply agency. However, in many circumstances, at local level in developing countries, the surveillance agency may carry out some of the necessary work, even including practical control measures, simply because it happens to be on the spot at the time. Normally, at this local level, the actual sampling and testing of the water should be the responsibility of the surveillance agency. This is because, in many developing countries, the local surveillance agencies are likely to be more active than any local water-supply agency. However, the ultimate responsibility of the surveillance agency should be to ensure that the responsible water-supply agencies control their drinking-water supplies to the best of their ability at all times.

Fig. 2. Flow chart for communications and action related to water-quality surveillance
2. WATER-QUALITY SURVEILLANCE

The level of training of those concerned in sanitary inspections often needs to be higher and more specialized than in the case of water-quality sampling alone. In the case of sanitary inspections carried out by the surveillance agency, those responsible should be at the level of a regional laboratory, and preferably even higher.

The actions taken and the lines of communication for the surveillance agencies and water-supply agencies are shown in Fig. 2.

2.4.3 Comprehensive information processing

In some countries, many regions have qualified staff to carry out surveillance but, in others, such staff will be available only at the central level. To avoid difficulties in communication, every effort should be made to ensure that the transmission of information is as direct and simple as possible. In small communities, it is usually recommended that the sanitary inspections carried out by or for the surveillance agency should not be the responsibility of local personnel.

It is most important that the bodies responsible for surveillance ensure that any instructions they issue, whether written or verbal, are clearly understood. This should help to avoid any misunderstanding and conflict between the different activities of the various bodies. Cooperation and collaboration among the different bodies is of great importance and should be fostered so as to ensure a good working relationship. If any negligence is found, this should be immediately and thoroughly investigated with the aim of correcting the situation and improving conditions for the future.
3. SANITARY INSPECTIONS

Broadly speaking, a drinking-water quality-control programme involves two equally important activities: the carrying out of sanitary inspections and the sampling and analysis of water. Variations in the quality of water supplies can help in detecting contamination problems, and in determining whether these have arisen at the source, during water treatment, or in the distribution system. However, it may often not be possible to take more than a few samples, and consequently the results of any analysis may not be representative of the water-supply system as a whole. Furthermore, microbiological analyses, since they take a considerable time to carry out, provide at best an indication of the water quality several days before. Because of this delay, and where the level of bacteriological contamination is found to be very high, it is possible that adverse effects may already have occurred in the population drinking the water. This limits the usefulness of bacteriological analysis as the sole indicator of the safety of a water supply.

Sanitary inspections, while they cannot replace water-quality analyses, are an essential complement to such analyses as part of water-quality control programmes. They allow for an overall appraisal of the many factors associated with a water-supply system, including the waterworks and the distribution system. Moreover, such an appraisal may later be verified and confirmed by microbiological analyses, which will indicate the severity of the defects. Sanitary inspections thus provide a direct method of pinpointing possible problems and sources of contamination. They are also important in the prevention and control of potentially hazardous conditions, including epidemics of waterborne diseases.

Sanitary inspections are intended to provide a range of information and to locate potential problems. The data obtained may identify failures, anomalies, operator errors, and any deviations from normal that may affect the production and distribution of safe drinking-water. When the inspections are properly carried out at appropriate regular intervals, and where the inspector has the knowledge necessary to detect problems and suggest technical solutions, the production of good quality water is ensured.

3.1 Organization

The frequency of routine sanitary inspections depends on a number of factors, such as geography, distribution of the population, access to the various localities, etc., as well as on the overall development level, including
facilities, number and expertise of technical staff, level of activity in surveillance programmes, etc.

In general, it is not possible to maintain the same level of activity in all areas of each country, and this can lead to difficulties in carrying out the programme. Nevertheless, a general approach has been described in Chapter 2. It may be impractical or difficult to initiate and carry out a comprehensive programme in countries that have numerous rural systems and only a few sanitary engineers or well-trained surveillance personnel. However, experience has shown that surveillance is feasible, at least in part, even with low programming levels, provided that a few simple precautions are taken.

For example, in a country or region where there are only a few highly trained professionals available for carrying out the control of a large number of localities, the use of less qualified technical personnel trained in surveillance can help. Collective training of selected groups of people has a multiplying effect so that, by means of short intensive courses, a single sanitary engineer can ultimately have a large number of auxiliary workers at his disposal. A fairly common alternative is for each region to have only one inspector (sanitary engineer, sanitarian or well-trained technician). The sole task of this inspector would be constantly to tour the various systems in the region.

Routine inspections are visits made with a defined frequency in accordance with a previously established plan. In addition, non-routine visits by the inspector will be necessary in atypical situations, such as the introduction of a new water source, and in cases of emergency.

Emergency situations calling for the urgent presence of the engineer or technician include:

(a) reports of epidemics;
(b) high turbidity caused by floods;
(c) unresolved cases where bacteriological analyses repeatedly show the presence of excess levels of microbiological organisms and where residual chlorine levels remain consistently low;
(d) the detection of any important changes that could impair drinking-water quality.

Surveillance personnel for rural water-supply systems can thus be divided into two types: inspectors for routine work and inspectors for non-routine and emergency situations. All the emergency situations mentioned are unusual and unpredictable, and can involve considerable health risks for the population. It is precisely this high risk potential that calls for greater attention and knowledge on the part of those making the inspections. Consequently, inspections in emergency situations should be conducted by a sanitary engineer or a professional with similar training. Such a person’s knowledge of the possible causes of the problem will not only result in a more reliable assessment of the situation and facilitate remedial action but the most suitable way of dealing with the problem is also more likely to be found. Routine surveillance can, however, be perfectly well carried out by technical operators so long as they have received suitable training.
It should be pointed out that, in view of the responsibility which all such surveillance personnel will bear, their training must be very thorough. Ideally, training covering all aspects of water-supply and distribution systems should be given in the field, under the supervision of a sanitary engineer.

Finally, it should be stressed that, while the operators carrying out routine sampling for bacteriological analysis may not have the same knowledge and training as the sanitary inspection staff, they should have a basic knowledge of the subject, and in many cases, will be able to give adequate warning of possible risks.

3.2 Methodology

Sanitary inspection requires a thorough examination of the water-supply system, or at least its key points, in order to check whether the installations are satisfactory and whether the various operations are being carried out properly. The recommended method of undertaking an inspection is to follow the natural sequence, starting with the source water and its intake, and going on to treatment, disinfection, storage, distribution, etc. In each case it is essential to record what has been observed on appropriate forms.

The procedures for carrying out sanitary inspections should be formulated in such a way that the inspector can make a rapid, systematic and complete assessment of the key points of any water-supply system. He or she should be able to construct a table or form which can be put together like a jigsaw puzzle, and which will then be specific to the water-supply systems under consideration. One example of such a form is provided in Annex 2, which also gives detailed information on the planning and implementation of sanitary inspections.
4. COLLECTION OF WATER SAMPLES

4.1 Basic requirements

One of the key elements in the quality control of drinking-water is the microbiological examination of the water. This is effected by analysing water samples collected from the water-supply system. In collecting such samples, the following requirements should be satisfied:

(a) sampling should be properly planned and, ideally, carried out with sufficient frequency to enable any temporal (seasonal) variations in the quality of the water to be detected;
(b) samples should be collected, stored, and dispatched in suitable sterilized bottles;
(c) the volume of water collected should be large enough to permit an accurate analysis;
(d) the sampling points in the water-supply system should be selected such that the samples obtained are as representative as possible;
(e) great care should be taken during sampling to prevent contamination of the sample being collected;
(f) in order to prevent any significant change in the composition of a collected sample prior to its analysis, it is important to ensure that it is collected properly, and dispatched as soon as possible;
(g) the sample details should be adequately described and the sample bottle properly labelled to avoid errors.

Detailed instructions for sampling are given in Annex 3, while general recommendations on various aspects of the sampling process are given below.

4.2 Sampling point selection

The objective of sampling is to determine the quality of the water arriving at the user's tap or other outlet, which may or may not be the same quality as that in the distribution system at the point where it is connected to a domestic dwelling. In many localities a domestic storage tank is commonly used and the water may become polluted there. Thus, to determine the quality of tap water, it would be necessary to check the quality of the water from every tank in the community, which is not feasible. Consequently, a water-quality control programme is designed to determine the quality of the water entering the user's dwelling. The quality of the water in any storage tank is the responsibility of the owner and occupants of the dwelling; this responsibility should be guided and encouraged by health education campaigns organized
by the public health authorities. For information on the frequency of sampling, see Table 4, p. 12.

In selecting sampling points, each locality should be considered individually; however, certain general criteria are usually applicable, as follows:

(a) sampling points should be selected such that the samples taken are representative of the different sources from which water enters the system;
(b) these points should include those that yield samples representative of the conditions at the most unfavourable places in the system, from the viewpoint of possible contamination (loops, reservoirs, low-pressure zones, ends of the system, etc.);
(c) sampling points should be uniformly distributed throughout the system;
(d) sampling points should be located in the three types of distribution system (open, closed and mixed) in proportion to the number of links or branches;
(e) sampling points should generally be chosen such that the samples are adequately representative of the system as a whole and its main components;
(f) sampling points should be located in such a way that water can be sampled from reserve tanks and reservoirs, etc.;
(g) in systems with more than one water source, the sampling points should be located so as to take account of the number of inhabitants served by each source;
(h) there should be at least one sampling point directly after the clean-water outlet from each treatment plant.

Examples are shown in Fig. 3–5 to illustrate the selection criteria for the sampling points in each of the three types of system.

In open distribution systems sampling is necessary:
A: at the clean-water outlet from the treatment plant; this serves to check the effectiveness of the water treatment and to indicate the quality of the water entering the distribution system;
B: at a point such that samples are representative of the water in the chief main;
C: at a point such that samples are representative of the water in the branches of the chief main;
D: at a point such that samples are representative of the water at the end of the system.
In closed distribution systems sampling is necessary:

A: at the clean-water outlet from the treatment plant; this serves to check the effectiveness of the water treatment and to indicate the quality of the water entering the distribution system;
B: at a point such that samples are representative of the water in the chief branch;
C: at a point such that samples are representative of the water in the secondary branches.

In this example of a mixed distribution system there are three water sources, and the system has both a "closed" distribution zone and one of the "open" type. Sampling is then necessary:

A: at the clean-water outlet from the treatment plant; this serves to check the effectiveness of the water treatment and to indicate the quality of the water entering the distribution system;
B: at a point such that samples are representative of the quality of the well-water entering the system;
C: at a point such that samples are representative of the quality of the water leaving the reservoir; in some cases it may also be important to take samples of water entering the reservoir;
D: at points such that samples are representative of the water in the main system; these points in the network should have equal importance in terms of amount of water flowing past them;
E: at a point such that samples are representative of the quality of the water in the open system (in this simple case samples should be taken from a secondary branch and at the end of the system).

This system is probably more complicated than most small-community
water supplies; it is included here to show how the most complicated situations may be dealt with.

4.3 Equipment

Although certain types of plastic bottle can be employed for sampling, it is best to use glass bottles; these should have securely fitting stoppers or caps, and both the bottles and their stoppers or caps should be adequately sterilized. The bottles should be capable of holding at least 200 ml of water.

If the sample taken for microbiological analysis contains any residual chlorine, the latter will continue to act on any bacteria present after sampling; this means that the analysis may not be indicative of the true microbiological content of the water sampled. To overcome this difficulty it is common procedure to add sodium thiosulfate to the sample; this reagent will immediately inactivate any residual chlorine present, but will not affect the microorganisms in the sample, whether chlorine is present or not.

4.3.1 Sterilization procedure for sample bottles

For a sample size of 200 ml, 4 or 5 drops of aqueous sodium thiosulfate solution (100 g/litre) are added to each clean sample bottle. The stopper is inserted loosely and, in order to prevent the entry of dust, a brown paper or aluminium foil cover is tied to the neck of the bottle. The bottle is then sterilized in a hot-air oven for one hour at 170°C, or in an autoclave for 30 minutes at 120°C. If an autoclave is not available, as a last resort, a pressure cooker can be used, but sterilization will then take 30–45 minutes. In order to prevent the stopper from getting stuck during sterilization, a strip of brown paper (75 x 10 mm) should be inserted between the stopper and the neck of the bottle.

For reasons of cost, bottles should be reused after the sample has been analysed in the regional or central laboratory. They should be resterilized in the laboratory and then returned to the place from which they came.

If, in unusual circumstances, it is not feasible or is too costly to return the bottles for reuse other types of bottle may be used for sampling. For example, the disposable types of glass bottle used for carbonated drinks or beer are available in a number of countries and have several advantages: they are made of glass; their capacity is often conveniently 250–450 ml; and they can be obtained in large quantities. However, a supply of caps and a manual capping machine are then needed. These bottles are sterilized by first adding the sodium thiosulfate solution and then standing them (uncapped) in the autoclave or hot-air oven, using a brown paper cover firmly attached by means of a string. The caps are sterilized separately, and then wrapped in brown paper.
4. COLLECTION OF WATER SAMPLES

4.3.2 Packing of sample bottles for transportation

Bottles should be transported or dispatched in a strong box, to prevent breakage; there should be sufficient space in the box to include bags of freezing mixture to keep the samples cool. Boxes holding 6 or 12 bottles are ideal. The outer cover may be of wood or metal and should bear the clearly written inscriptions, “Fragile”, “Water samples urgent”, and “This side up”, as well as the address of the laboratory to which the bottles are to be sent. A reversible plate should be fitted on the box lid, bearing the name and address of the person dispatching the water samples on one side, and that of the water analysis laboratory on the other. The lid should have a handle to help ensure that the box is carried the right way up. An example of a suitable box for sample transport is shown in Fig. 6.

Fig. 6. Protective box for sample transport

4.4 Dispatch of samples

Many water-quality parameters may change during the time that samples are in transit to a laboratory; field testing can avoid the need to send samples for testing but, if this cannot be done, samples should be properly packed in strong boxes and sent to the laboratory as quickly as possible. If it is anticipated that they will be in transit for longer than 24 hours, special "holding" media should be used. The ideal temperature for sample storage is
Fig. 7. Suggested form to accompany water samples

WATER-QUALITY
CONTROL
PROGRAMME

(Name of body responsible ...............)

SAMPLING AND BACTERIOLOGICAL ANALYSIS

Sampling data:
Locality _______________________________
Sample site _______________________________
Place _______________________________
Source _______________________________
Sender _______________________________
Date collected _______________________________
Hour collected _______________________________
Date of analysis _______________________________
Time of analysis _______________________________
Residual chlorine _______________________________ mg/litre

Results:
TOTAL COLIFORMS........_________/100 ml
FAECAL COLIFORMS........_________/100 ml
(OTHER)................_________

Laboratory Sample No. ________

WATER BACTERIOLOGICALLY
GOOD - BAD

ACTION TAKEN
_________________________________
_________________________________
_________________________________

(WHO 85348)
4. COLLECTION OF WATER SAMPLES

4–10°C; in hot climates, bags containing a precooled freezing mixture should be placed around the samples in the transport boxes, as shown in Fig. 6.

In many places, those responsible for sampling do not have vehicles for the transportation of sample bottles, and consequently public transport has to be used. This means that careful attention must be paid to timetables and routes.

In order to ensure that every sample is clearly and adequately described, it should be accompanied by a detailed form, which should contain all the necessary information on where and when the sample was collected, as well as a description of the sample and the name of the person who dispatched it. A form, which has been tested in practice and found to be satisfactory, is shown in Fig. 7. It contains two sections which can be separated; at the time of sampling, the same data are entered in both sections. The smaller section is then detached and, if already gummed, is stuck directly on the bottle, or otherwise affixed with a suitable adhesive; this information will be useful to the laboratory carrying out the analysis. On the second, larger, section of the form, the laboratory performing the analyses enters the results together with information on any actions that have been taken. Copies are then sent to the local surveillance agency or water-supply agency and the person responsible for sampling, thus providing them with all the necessary information on the samples.
5. BACTERIOLOGICAL ANALYSIS

The importance of waterborne diseases has long been recognized. The main causes of human enteric diseases are pathogenic microorganisms. Contamination of drinking-water by human or animal excrement constitutes the most common mechanism for transmission of these organisms to humans, not only directly, but also indirectly, through food preparation. The primary objective of the bacteriological examination of potable water is thus the detection of faecal pollution. Although it is possible to detect the presence of various pathogens in water, the isolation and identification of many of them are often extremely complicated and seldom yield quantitative results. An indirect approach is therefore taken in assessing the risks associated with drinking-water contaminated by enteric pathogens, based on the assumption that the estimation of groups of normal enteric organisms (indicator organisms) will indicate the level of faecal contamination of the water supply. Thus the estimation of such organisms provides an indirect indication of the risk from waterborne enteric pathogens.

5.1 Choice of indicator organisms

The coliform organisms are the most commonly measured indicators of water quality, although experience has shown that they are not completely satisfactory for this purpose. Total coliforms are defined as Gram-negative bacteria that ferment lactose at 35 or 37°C, with the production of acid, gas, and aldehyde within 24–48 hours. They are cytochrome-oxidase negative and non-spore-forming.

Faecal coliforms (thermotolerant coliforms) are a subgroup of total coliforms, having the same properties except that they tolerate and grow at the higher temperature of 44–44.5°C, and form indole from tryptophan; organisms possessing these combined properties are regarded as presumptive *Escherichia coli*. The presence of *E. coli* itself can be confirmed by special tests, as described in Volumes 1 and 2 of the guidelines.\(^a\)

The total coliform group includes several genera, all of which may be of faecal origin. Under suitable conditions these can multiply in the presence of organic material. Some coliform species are frequently associated with plant

\(^a\) Guidelines for drinking-water quality, Geneva, World Health Organization, 1984 (Vol 1 Recommendations, p 18 Vol 2 Health criteria and other supporting information, p 16)
debris or may be common inhabitants in soil or surface water. Thus, the total coliform group should not be regarded as an indicator of organisms exclusively of faecal origin, especially in very hot countries where coliforms of non-faecal origin may abound. The use of total coliforms as an indicator may therefore be of little value in assessing the faecal contamination of surface water, and especially of water in unprotected shallow wells, where contamination by coliforms of non-faecal origin can often readily occur. However, it may be of value for deep-well water, although even this water may occasionally become contaminated with non-faecal coliforms. The measurement of total coliforms is of particular relevance for treated and chlorinated water supplies; in this case the absence of total coliforms would normally indicate that the water has been sufficiently treated/disinfected to destroy the various pathogens.

Measurement of faecal coliforms specifically is a better indicator of general contamination by material of faecal origin. While the predominant species is Escherichia coli, which is exclusively of faecal origin, strains of Klebsiella pneumoniae and Enterobacter species may also be present in water contaminated by faecal material. It should be remembered that Klebsiella pneumoniae and Enterobacter strains may be associated with composting organic materials and water-soaked wood, especially in hot climates, as is reported to occur in parts of India. However, since the bacteriological analysis of unchlorinated water is normally carried out at the same time as a sanitary inspection, there is generally little difficulty in interpreting the results.

Ideally a drinking-water supply should be free of faecal coliforms. It may not always be practical, however, to achieve this aim in developing countries, especially in rural areas. Thus, for an interim period, it may be necessary to establish a different standard as a tolerance level. When such an interim tolerance level is established, the quality of alternative water sources should be borne in mind. In addition, it is important to consider whether treatment of a suspect source can be reliably carried out.

The following are common examples of the highly undesirable levels of contamination found even in protected water supplies: protected spring water without chlorination may (not unusually) contain 10 faecal coliforms per 100 ml of water, and protected surface water may have a count of more than 1000 faecal coliforms per 100 ml. In some instances, it may be relevant to supplement the faecal coliform count with measurements of other groups of organisms, e.g., faecal streptococci. However, the faecal streptococci include other species which may multiply in soil and surface water, especially in combination with plant debris decay material. The streptococci of faecal origin have, however, a longer survival time in groundwater than faecal coliforms. These considerations may be relevant in many rural areas.

For reasons of simplicity the microbiological methodology for small-community water supplies outlined here is limited to the coliform group, since this group is better known and also relatively easily measured. Normally, when coliforms are detected in water, adequate information is then available to make the necessary decisions regarding remedial action, particularly when the results of a concurrent sanitary inspection are also available.
For water subjected to treatment culminating in disinfection, including water in the distribution system, the determination of total coliforms may be adequate for checking its quality. However, contamination of the water in the distribution network may arise because of defective joints between pipes, pipe breakages, cross-connections, back-siphonage, defective reservoirs, etc. The pollutants thus introduced may react with the chlorine in the water and can rapidly reduce the residual chlorine to zero. In these circumstances it is important to assess whether the contamination is of faecal origin or not; if faecal contamination is suspected, then both total and faecal coliforms should be measured in the treated and/or disinfected water supplies, and in the distribution systems (see Fig. 8).

For untreated, unchlorinated supplies, such as surface water or shallow- or deep-well waters, the detection of faecal coliforms alone can generally serve as an adequate guide for determining whether pathogenic organisms are present in the water (see Fig. 9).

**5.2 Methods of analysis**

Two methods have been developed for the detection of indicator bacteria in water: *(a)* the multiple-tube (MT) method; and *(b)* the membrane-filter (MF) method. Their field application is described in Annex 4 and detailed descriptions given in Annexes 5 and 6 respectively. In what follows, a brief account of their advantages and limitations is provided, together with practical guidance on the choice of method in various situations.

**5.2.1 Multiple-tube method**

In the multiple-tube method different amounts of water are added to tubes containing a suitable culture medium. The bacteria present in the water reproduce and, from the number of tubes inoculated and the number with a positive reaction, the most probable number (MPN) of bacteria present in the original water sample can be determined statistically.
The multiple-tube method is applicable to all kinds of water sample: it can be used with clean, coloured, or turbid water containing sewage or sewage sludge, or mud and soil particles, provided that the bacteria are homogeneously distributed in the prepared test samples. Theoretically, the technique is sufficiently sensitive to measure low levels of bacteria in water samples, although bigger containers holding larger volumes of sample then need to be used as culture vessels; however, in normal circumstances, 10 ml is usually the largest volume used.

5.2.2 Membrane-filter method

In this method a measured volume of water is filtered through a membrane which retains the bacteria on its surface. The membrane is then incubated on a suitable selective medium, allowing the bacteria to reproduce and to form colonies. The number of colonies counted is directly related to the bacteriological content of the water sample being analysed. This method has not been as extensively used as the multiple-tube method. It is not suitable for turbid water but may otherwise have several advantages. Its particular
Fig. 10. Decision network for selecting method of bacteriological analysis
advantages and limitations are as follows:

(a) Advantages
—results are obtained more quickly; the number of coliforms can be assessed in less than 24 hours, whereas the multiple-tube method requires 48 hours, irrespective of whether a negative or a presumptive positive result is obtained;
—it reduces the work required and leads to savings in certain supplies and glassware;
—it gives direct results;
—it is easy to use in laboratories, or even in the field using portable equipment.

(b) Limitations
—high turbidity caused by clay, algae, etc., prevents the filtration of a sufficient volume for analysis and may also produce a deposit on the membrane that could interfere with bacterial growth;
—the presence of a relatively high non-coliform count may interfere with the determination of coliforms;
—in rural areas it may be difficult to obtain suitable membrane filters and, in addition, they may be relatively expensive;
—water may contain toxic substances that may be absorbed by the membranes and affect the growth of the coliforms.

5.3 Selection of method

Normally, the bacteriological analysis of water should be carried out in a laboratory. In remote areas where transportation facilities are lacking, a simplified analysis can be carried out locally using portable equipment; such field tests for bacteriological analysis are described in Annex 4.

To aid the selection of the procedure and methods to be used, a schematic decision network is shown in Fig. 10. The purpose of this diagram is merely to provide suggestions for the approach to be used; local or other circumstances may also affect the final decision.
6. DETERMINATION OF RESIDUAL CHLORINE

6.1 Behaviour of chlorine in water

Disinfection of water supplies is the most important barrier against pathogenic bacteria and viruses; chlorine, in one form or another, has been the main disinfecting agent employed in most countries.

The pre-eminence of chlorine as a disinfectant is doubtless explained by its ready availability, cheapness, and reliability, as well as the ease with which it can be used and measured in water supplies. In relation to its analytical determination, it is important to understand the manner in which chlorine or chlorine-releasing substances behave when added to water, depending on the other substances present.

(a) When the water contains certain reducing substances, such as ferrous salts or hydrogen sulfide, these will reduce part of the added chlorine to chloride ions.

(b) When the water also contains other substances capable of reacting with chlorine, such as ammonia and its derivatives, organic matter, bacteria, etc., the level of free chlorine will be decreased, and some chlorinated organic compounds may be produced.

(c) If the quantity of chlorine added is sufficiently large to ensure that it is not all reduced or combined, a portion of it will remain free in the water; this is termed residual free chlorine or free chlorine.

When chlorine reacts chemically as in (a) or (b) above, it loses its oxidizing power, and consequently its disinfecting properties. Compounds formed by a combination of chlorine with ammonia derivatives, however, still retain some disinfecting properties. Chlorine present in this form is termed residual combined chlorine or combined chlorine.

When there is an excess of other types of reactive compounds relative to the chlorine added originally, the free chlorine level will decrease to zero.

The free chlorine plus the combined chlorine is termed total residual chlorine. From the viewpoint of disinfection, the form of most interest is the free chlorine, since its bactericidal power is higher than that of combined chlorine; consequently, routine analysis always aims at determining at least the free chlorine level.

6.2 Methods

Free chlorine in aqueous solution is unstable and the chlorine content of water samples, particularly weak solutions, will decrease rapidly. Exposure to sunlight or other strong light, or agitation will accelerate the reduction of the chlorine content. Analysis of water samples for chlorine should therefore be
carried out immediately after sampling. Samples should not be stored to be analysed later. Although there are several techniques and suitable reagents for determination of residual chlorine, only three field methods are described, namely those using $N,N$-diethylparaphenylenediamine (DPD), orthotolidine (OT), and starch-potassium iodide.

With the first two reagents, photocolorimetry or spectrophotometry can be used, both of which can be conveniently carried out in the field using commercial visual comparators and/or simple test-tube comparison methods. In the analysis using DPD, the reagent may be a solid or a solution. Both are available commercially; the solid is more stable but the solution is more readily available and for this reason is recommended. The solution should be kept in brown bottles and should be thrown away when it starts to become obviously discoloured. Both reagents (DPD and OT) can be used with water samples in the pH range 6.5–8.5, without any special buffering.

In view of its carcinogenic properties, OT has been abandoned in many countries and preference is generally given to DPD. If OT is still used, very special care should be taken in handling it. It is essential, in particular, to ensure that OT is never dispensed by means of a mouth pipette; inhalation or exposure to the skin must be avoided.

If a standard commercial visual comparator is used, the test can be rapidly and easily carried out by personnel with only a minimum of training. With the OT method, the estimated concentration of free chlorine may be somewhat high because of interference from any combined chlorine present. However, this interference can be minimized by carrying out the test as quickly as possible, since combined chlorine reacts more slowly than free chlorine. If a high concentration of combined chlorine is suspected, the sample may also be chilled to about 1°C (prior to adding the OT) since this minimizes the error from any combined chlorine present.

The original test-tube comparison technique makes use of Nessler tubes, but ordinary test-tubes can also be used. The accuracy of the determination may be somewhat less with ordinary test-tubes, but extensive experience in several countries has shown that it is nevertheless acceptable. Furthermore, the small size of test-tubes makes their transportation easy, and their lower cost allows for increased field-testing.

The visual comparison methods are suitable only for relatively clear and uncoloured water, since highly turbid and coloured water will mask the colour developed in the test. Normally, the colour developed is matched against standard discs or tubes; experienced operators can get accurate results without colour-matching.

The starch–potassium iodide field method suffers from the disadvantage that it is not specific for residual free chlorine; in fact, it measures the total of combined and free chlorine and consequently may give a falsely high concentration. Because the method can give a false positive result, it may give rise to an unjustified sense of security when free chlorine is not present; the method is consequently not normally recommended, and is included here simply because it is very easy to carry out, and the reagents are cheap and readily available.

Full details of all these tests are given in Annex 7.
7. REMEDIAL AND PREVENTIVE MEASURES

The purpose of the surveillance of drinking-water supplies is to control the quality of the water and thereby protect the consumers. If the sanitary deficiencies identified by such surveillance are not remedied, the effort put into the programme has been wasted. What is then worse, perhaps, is that the situation may become dangerous, because the community will be aware that a surveillance programme has been carried out, and this may lull them into a false sense of security. Failure to complete remedial measures following surveillance is not uncommon. In essence, the reasons for poor water quality should be identified, the cause corrected or eliminated and, where necessary, emergency precautions taken.

Any remedial measures that may be necessary are a direct consequence of the evaluation of the bacteriological tests and of the sanitary inspections. Remedial measures, carried out either by the water-supply agency or the surveillance agency, are essential where problems have been identified. Examples of such measures are the selection of safe and adequate sources; constant vigilance; checking of disinfection through residual chlorine tests; community education and primary health care programmes; bacteriological analysis after remedial measures have been implemented; warnings to the community to boil the water or add disinfectant wherever a serious problem occurs; and sanitary checks to ensure that remedial measures have been carried out properly.

7.1 Remedial measures

Good judgement is demanded on the part of the inspector in deciding on the importance of any deficiencies found. If serious deficiencies are discovered, the cost of the various possible corrective measures should be evaluated. A decision regarding the urgency of implementing a corrective measure is of paramount importance. This should be a very carefully considered judgement, bearing in mind that in some cases a serious epidemic may ensue if remedial measures are not implemented immediately. In other cases it may not be so urgent to carry out complete remedial measures, and any equipment that may be required can be transported economically rather than by express services. The urgency of various typical remedial measures is indicated in Table 5.

Some examples of remedial measures that need to be carried out immediately are cleaning and disinfection of dug wells; removal of any cross-connections; warnings to the community to boil water; disinfection of
collected drinking-water by the community; confirmation that remedial measures have been implemented and that they are effective, by means of bacteriological analysis and/or residual chlorine testing; and the introduction of further sanitary checks.

7.2 Preventive measures

Clearly, some remedial measures are less urgent than others and these can be introduced over a period of time, providing what may be called preventive measures. Surveillance agencies should arrange the necessary feedback or other forms of communication to the agencies responsible for improving the technology and ensuring that codes of practice are strictly followed.

A number of different pollution situations have been identified in Table 5 and the most typical remedial and preventive measures listed. Certain other measures may also be needed and these will depend on the local situation. The recommended measures are divided into immediate remedial measures and preventive action for avoiding recurrence of contamination.

7.3 Control of biological hazards

No standard methods for the detection of pathogenic protozoans and helminths in water supplies are available that could be applied as part of a routine surveillance programme for small communities. Remedial and preventive measures are therefore the method of choice in controlling such biological hazards. For further information, see Volume 1 of the guidelines.a

7.3.1 Protozoa

Groundwater supplies can be protected by following established sanitary engineering practices in the construction and maintenance of such supplies. Where faecal contamination is likely or unavoidable, diatomaceous earth filtration, sand filtration with coagulation and sedimentation, or slow sand filtration has been shown to be effective in removing a high percentage of pathogenic protozoa. Available data on Entamoeba histolytica and Giardia indicate that these organisms are considerably more resistant than bacteria or viruses to inactivation by chlorination at the residuals and contact times recommended for the latter. Such chlorination may not therefore provide adequate protection against transmission of these agents by drinking-water. In particular, water supplies treated by pressure filtration and chlorine disinfection have at times been implicated in waterborne outbreaks of giardiasis. Special care should therefore be taken with process control where

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Table 5. Remedial and preventive measures for protection of water supplies

<table>
<thead>
<tr>
<th>Source and mode of supply</th>
<th>Evidence or information available</th>
<th>Immediate remedial measures</th>
<th>Preventive action for avoiding recurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>open dug wells</td>
<td>pollution usually expected to occur</td>
<td>(a) clean well if necessary and shock-chlorinate, followed by continuous chlorination, (b) recommend boiling of drinking-water, use of disinfectants and/or filters in the home</td>
<td>convert to a protected, covered well with hand-pump or device for raising water isolated from the user, discourage construction of new open dug wells, promote community education and participation</td>
</tr>
<tr>
<td>unpiped supplies from covered wells or shallow or deep tubewells with hand-pumps or motorized pumps</td>
<td>findings of sanitary inspection unsatisfactory</td>
<td>confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home, (a) if an alternative safe supply is not available, recommend boiling or use of disinfectants in the home, (b) confirm bacterial quality, (c) conduct a detailed sanitary inspection and remedy shortcomings found</td>
<td>eliminate pollution sources and/or repair well if necessary to remedy shortcomings found in sanitary inspection, (a) take opportunity to promote community education and participation, (b) feed information on the episode and sanitary survey results back to the water-supply agencies to help in deciding whether the technologies used and the codes of practice followed are appropriate</td>
</tr>
<tr>
<td>untreated piped supplies</td>
<td>findings of sanitary inspection unsatisfactory</td>
<td>confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home, (a) chlorinate supply if feasible or recommend boiling or disinfection in the home, (b) conduct a detailed sanitary inspection and remedy shortcomings found</td>
<td>eliminate pollution sources and/or repair system, if necessary, to remedy shortcomings found in sanitary inspection, protect the source and its catchment (this is very important)</td>
</tr>
<tr>
<td>unsatisfactory bacteriological quality of water at source</td>
<td>unsatisfactory bacteriological quality of water in the distribution system</td>
<td>(a) if source is unsatisfactory, proceed as above, (b) if source is satisfactory but distribution system is suspected, chlorinate supply or recommend boiling or disinfection in the home, (c) conduct a detailed sanitary inspection of distribution system and remedy shortcomings found</td>
<td>frequent and improved supervision of the distribution system and prompt repair and maintenance are essential, especially for intermittently operated systems</td>
</tr>
<tr>
<td>localized epidemic of enteric infection</td>
<td>(a) take sample for bacteriological quality determination, without waiting for this result, chlorinate general supply or recommend boiling or disinfection in the home</td>
<td>(a) take opportunity to promote community education and participation, (b) feed information on the episode and sanitary survey results back to the water-supply agencies to help in deciding whether the technologies used and the codes of practice followed are appropriate, (c) conduct a detailed sanitary inspection of distribution system and remedy shortcomings found</td>
<td>frequent and improved supervision of the source and distribution system if necessary, careful operation and maintenance of such systems are essential, especially for intermittently operated systems</td>
</tr>
</tbody>
</table>
treated piped supplies

findings of sanitary inspection of source, treatment plant and/or distribution system unsatisfactory

confirm bacteriological quality and if necessary recommend boiling or use of disinfectant and/or filters in the home

unsatisfactory bacteriological quality* of water after treatment or in the distribution system

(a) ensure adequate chlorination of general supply or recommend boiling or disinfection in the home

(b) conduct a detailed sanitary inspection of whole system and remedy shortcomings found

localized epidemic of enteric infection

(a) take sample for bacteriological quality determination; without waiting for this result, chlorinate general supply or recommend boiling or disinfection in the home

(b) conduct a detailed sanitary inspection of source and distribution system, and remedy shortcomings found

untreated community
rainwater collection systems

localized epidemic of enteric infection

chlorinate water in collection reservoir (tank, container, etc.), or recommend boiling or disinfection in the home

(a) ensure that collection surfaces are in a sanitary condition and that bypass for initial collected water is properly operated

(b) promote community education and participation

(a) frequent and improved supervision of the whole system is necessary; careful operation and maintenance are essential for intermittent systems

(b) ensure that routine sanitary inspections are carried out

(c) feed information back to the water-supply agencies

* In accordance with recommended guidelines, the quality of water is regarded as "unsatisfactory" if a positive result obtained on a sample is confirmed on repetition
there is a possibility of contamination of raw water by enteric protozoa, particularly where disinfectant residuals are low.

Where disease outbreaks are the result of contamination of drinking-water with pathogenic intestinal protozoa, boiling of water may provide effective control by inactivating Giardia, E. histolytica, and Balantidium coli. Attempts should be made to identify and remove sources of contamination. Sanitary inspections should be conducted to identify and correct deficiencies in treatment and in the distribution system.

7.3.2 Guinea-worm

Dracontiasis (guinea-worm infection) is a problem of small unpiped water supplies (e.g., step wells or reservoirs) where regular surveillance is often impracticable. A single infected copepod containing one larva is capable of infecting man with Dracunculus, though the worm burden will depend on the number of infective larvae ingested and their sex. Since one fertilized adult female guinea-worm can cause severe disease, infective stages should be absent from drinking-water. As this is the sole route of transmission to man for Dracunculus, it is a matter of importance. In view of the way that rhabditiform larvae reach the copepods (by being washed into wells from the limbs of those drawing water), it is clear that source protection is the best approach to prevention. The use of well surrounds that rise above ground level and drain away from the well usually suffices, though capping the well and fixing a pump is preferable. In emergency situations the infected copepods may be killed by addition of granules of the pesticide temephos to wells in the doses required for insect larva control. The use of double-thickness cotton cloth to filter drinking-water has also proved to be successful in some cases.
8. COMMUNITY EDUCATION AND INVOLVEMENT

The goal of water-supply programmes is to ensure that convenient, year-round access to adequate quantities of good-quality water is available to all. While convenience, quantity and year-round availability of water will be readily appreciated by most users, water quality may not be so easily identified. To many people the quality of water can only be assessed in terms of its aesthetic characteristics, i.e., clarity, colour, turbidity, taste, and odour. Water may meet such aesthetic requirements, yet still be unsafe in terms of its bacteriological and/or chemical quality. Thus, in addition to the installation of hardware, water-supply programmes need to contain a component of consumer information and education, which should aim to create an awareness of water quality and its relationship to health among those served by the water-supply system. Such awareness should lead to improved behaviour in preventing the contamination of water sources, in ensuring the cleanliness of public water outlets and the sanitary storage of drinking-water in the home, and possibly in preventing vandalism or damage to vulnerable parts of the water-supply system. The information and education programme should create an appreciation not only of the people's right to a safe water supply but also of their responsibility to use and maintain it wisely and well.

8.1 Community involvement

Surveillance of water quality has the objective of protecting drinking-water supplies from contamination to the greatest extent possible. When contamination occurs, effective surveillance provides an early warning which permits interventions aimed at reducing or eliminating hazards to human health. Some level of surveillance of drinking-water quality is the clear responsibility of the Ministry of Health. Few countries, however, have the resources needed to provide comprehensive surveillance coverage for all water supplies under their jurisdiction. Rural areas and small communities present a particular problem. Their remoteness from laboratories and the services of the responsible ministry, their small size and their large number in most countries make it difficult, if not impossible, for central government staff to carry out anything more than periodic surveillance.

The solution to these problems may be found in the concept of primary health care, which contains three elements that are equally applicable to water-quality surveillance. The first of these is health education, i.e., the
provision of information designed to arouse the desire of people to have safe water supplies. The second element is the provision of whatever technical assistance is necessary to help people to achieve their desire for safe water. The third is the use by the people in the community of their own skills and resources in actions aimed at improving their health, in this case actions that keep water supplies safe.

The entry point in community health education is the compilation of a community profile which describes the local perception of health problems and needs. This work will normally be the responsibility of the primary health worker. It is not intended that the profile should be used by government technocrats for the formulation of solutions to the community's problems. Instead, the profile is used as a basis for a dialogue with the community, which results in the community devising and deciding on actions that will overcome or circumvent the problems identified and satisfy the perceived needs. Water quality and water-related disease may not at first be perceived as priority problems. In this case, the health worker should not force the issue. It is far better to provide guidance and to lead the community to a recognition of the problem. In due course the community will come to realize the need to ensure that the water supply is safe.

Health education on water quality must recognize that the use of water for personal and domestic hygiene can also have an impact on health. Educational interventions must therefore avoid the danger of "overselling" the importance of any one aspect of water supply. A safe, convenient reliable water supply is a basic human need without which it is practically impossible to maintain a healthy environment. Nevertheless, it is not in itself sufficient to ensure good health; the water supply must be properly used for personal, domestic and community hygiene, accompanied by adequate nutrition and food sanitation, as well as by proper excreta disposal. Thus it is important for the health education programme to avoid creating an impression that water-quality surveillance will prevent illness. It can lead to an improvement in health status but does not solve all problems.

The improvement of health status resulting from safe water may first be reflected by a reduction in the incidence of infant and early childhood diarrhoea. In a recent controlled experiment, household water containers were regularly cleaned and refilled with chlorinated water, while a control group received a placebo of distilled water. The reduction in childhood diarrhoea in the group receiving the chlorinated water was 75% greater than in the placebo group. There have been very few controlled experiments of this nature. The results provide convincing evidence of the importance to health of disinfected drinking-water, preferably with a chlorine residual that will kill any pathogens present in the water container or on serving dishes. An interesting outcome of this experiment was that the placebo group recognized the improved health status of the group receiving chlorinated water and concluded that the waters were being treated differently. This led to a demand for similar treatment and all of the families were eventually given chlorinated water.

The results obtained in this experiment suggest an approach that can be followed by health workers concerned about water quality. With minimal supplies of hypochlorite solution and with the cooperation of some families in
8. COMMUNITY EDUCATION AND INVOLVEMENT

a community, stored water in demonstration homes could be made safe. If hypochlorite solution is not available, a substantial improvement in the bacteriological quality of water stored in the home can be achieved by exercising care in the cleanliness and handling of the storage container and its contents. The health improvement among the children in the demonstration families will not be lost on the neighbours. This will generate a demand for safe water, and the community will soon demonstrate its willingness to concern itself with source protection and similar surveillance activities. Patience is necessary, however, since the health benefits will be gradual; they may be barely recognizable from day to day but impressive over a period of six months to one year. For this reason the health worker must keep records to be able to demonstrate to mothers in the community the decreased incidence of illness among their children.

Meanwhile, health workers must observe the water-supply practices followed in the community. The water supply, its likelihood of becoming contaminated and the way it is used need to be noted and any shortcomings should be discussed with community leaders. Simultaneously, the bases of primary health care—cultural sensitivity, community self-help and appropriate technology—must be kept in mind. Once people are able to understand the relationships between water quality and disease, the introduction of surveillance and control measures becomes increasingly possible. Simple measures, such as the fencing of a water-collection point to keep out cattle, or the protection of a spring to exclude surface drainage, may be planned and implemented by the people of the community with guidance from the health worker. More complex tasks, such as the construction of a spring box or the installation of a sanitary water-storage container, may require technical and material assistance from the referral level of the health-care system or from the water-supply agency. The concept that must remain at the forefront of a surveillance and improvement programme is that the major responsibility rests with the community; government can only help the community in the achievement of its objectives.

8.2 Training rural community volunteers

As an understanding of the water/disease relationship grows, and people recognize a need for surveillance in order to maintain the good quality of the water supply, the community should be encouraged to increase its surveillance activities and improve the water system. Several options are available whereby such activities may be implemented. One is the selection of community volunteers to undertake the surveillance activities. Another is for the community to provide a stipend to a local worker to carry out whatever day-to-day tasks are needed. In either case, some minimal amount of training by the Ministry of Health or by the water-supply agency will be needed, as well as the establishment and maintenance of a reporting system. At the local level, some measure of management will be required through a community water committee, health committee, or similar structure.
The activities to be undertaken by the community volunteer will depend on the nature of the water supply. The general guidance provided during the training period should be supplemented by experience gained from working with the primary health worker or district sanitarian on a few of the surveillance exercises. For most rural supplies the main emphasis will be on:

- inspecting supplies in order to detect actual or potential contamination of water resulting from human or animal activities near the source of supply;
- devising and implementing, possibly with help from the community, methods for protecting the water source from contamination;
- advising water users on procedures that will prevent or diminish the chances of contamination of the water supply and the containers used to transport and store water;
- taking samples of water periodically for transport to the nearest laboratory for analysis; alternatively, tests may be carried out in the field if suitable equipment is available;
- reporting the findings of inspections to the local committee and the Ministry of Health and/or the water-supply agency;
- if the water supply is chlorinated, carrying out periodic field analyses for residual chlorine;
- informing the community of the results of analyses and inspections and explaining the implications of these results with respect to health, with the objective of stimulating involvement in actions to keep the water clean and safe.

8.3 Community health education

A variety of communication techniques is available for use by health educators in transmitting information to people. At one end of the scale is the "one-to-one" approach, in which an educator provides information to an individual; at the other is the use of mass media, such as television, radio and printed periodicals. Between these extremes are many intermediate techniques, such as group discussions supported by visual aids, health education in schools, production of posters and flip-charts, films, slide shows, audio cassettes, or traditional drama and music. No one approach can be claimed as the best way to conduct a health education programme. In many programmes several different approaches are used simultaneously and, on the basis of continuous evaluation, greatest emphasis may be placed on the approaches that appear to be most successful.

The community profile referred to above is the starting point for the detailed design of health education implementation at the community level, which will largely be the responsibility of the community health worker within the framework of primary health care. Other forms of education will be provided from the central level, e.g., health education that requires media, print, or film production. Thus coordination of an overall health education
programme must be undertaken by the health education unit to ensure that the information provided is both consistent and related to identified health problems.

Health education in schools is particularly important and often requires that teachers be given refresher training supported by appropriate teaching materials and visual aids. Pupils and students are in a learning environment and are generally receptive to education. Thus, health education in schools provides an effective and continuing reinforcement of the more intermittent delivery of health information by other means.

The central health education unit in the ministry is usually equipped to prepare visual aid materials for use by health workers. Materials that are useful to community health workers include flip-charts, flannelgraphs, posters and brochures. The health education unit must ensure that community health workers understand the information to be transmitted and also how to use the visual aid material provided to them. The orientation of both information and visual aids should be consistent with the primary health care strategy, which depends on the community to take actions for the improvement of community health. This strategy is especially applicable to water-quality surveillance and water-supply improvement, since these tasks do not generally require high levels of technical skill. The objective should therefore be to create a desire among people in the community to become involved in surveillance and control activities which they recognize as a means of improving their health.
ANNEX 1

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ANNEX 2

SANITARY INSPECTIONS

As outlined in Chapter 3, sanitary inspections are among the essential elements of an effective drinking-water quality-surveillance and control programme. In undertaking his tasks, the sanitary inspector has to prepare a form, tailored specifically to the small-community supply system to be visited and based on a general form that takes account of all possible procedures required for evaluating water-supply systems by simple and rapid methods. The various procedures are described in more detail below, accompanied by checklists, as appropriate.

1. Sources of water

1.1 Groundwater

Groundwater is generally the most suitable source for a small-community supply. It is essential, however, to protect these underground sources from the infiltration of any contaminating material. Consequently, the groundwater source should be as remote as possible from any source of pollution, such as latrines, septic tanks, sewage discharges, agricultural drainage-water discharges, etc.

Local geological knowledge is important in judging the potential impact of pollution sources in the vicinity of the well or other abstraction point. In particular, the direction of groundwater flow should be known to ensure that no pollution sources are situated directly upstream of the abstraction point. In areas of limestone and fissured rocks, special efforts should be made to ensure maximum possible distance between potential pollution sources and the groundwater intake. Judgement and experience are important since the necessary geological information is often not available.

Checklist for groundwater

Is the immediate vicinity of the abstraction point (well) free from any potentially polluting sources?

(Note: additional questions are given in section 2.1)

1.2 Surface water

Because of the open accessibility of surface waters and the ease with which they may become polluted, the water from such sources should preferably be
disinfected before distribution to consumers. The siting of the water-supply intake is of crucial importance. It should be upstream of, and as far away as possible from, sewage outfalls, industrial waste discharges, drainage run-off from agriculture, etc.

Surface-water intake pipes should be well secured, and sited well away from the river bank or lakeside. The mouth of the intake tube should be not less than 30 cm below the water surface, to prevent the entry of any floating matter. Intake points should also be far enough above the bottom to avoid taking in any mud. Even under the worst conditions the intake pump should be sufficiently powerful to resist the force of the current in the river at all times. If electric pump motors are used, they should be fully protected from moisture, etc.

Checklist for surface water
Is the intake correctly sited with respect to pollution outfalls?
Is the intake correctly placed with regard to depth and distance from the bottom?
Is the intake pipe firm and stable in position?
Is the intake system functioning properly?
(Note: additional questions are given in section 2.2)

1.3 Rainwater

The rainwater intake consists of a sloping surface leading into a tank or reservoir. All parts of the system should be clean and free from weeds, particularly if it is at ground level. There should be some technical means of diverting the water being collected, so that after a dry period the initial fall of rain can be allowed to drain to waste. This "first rain" washes and helps to clean the collecting surfaces. Only thereafter should rainwater be collected for supply purposes.

Checklist for rainwater
Is the rainwater collection surface free from weeds and dirt?
Is there a drain-off system for diverting the first portion of the rain to the waste drain?
(Note: additional questions are given in section 2.3)

2. Water collection and treatment

In accordance with the type of water source used and its potential for contamination, different technical structures and treatment installations will be required. During the sanitary inspection, the construction as well as the operation and maintenance of the installation must be carefully checked. The major features to be inspected are given below for the most common types of supply system.
2.1 Groundwater abstraction and treatment

Depending on the natural quality of the groundwater and on the likelihood of contamination, the water may require treatment and/or disinfection. In particular, open shallow wells are readily subject to contamination by humans, animals, etc., and a sanitary inspection would inevitably result in the identification of severe health hazards. Other systems for groundwater extraction, which allow better protection of the water source, are described below.

2.1.1 Dug wells

Dug wells are one of the most common well structures and are used worldwide for the abstraction of groundwater, providing small communities and individual homes with drinking-water. The dug well provides water from a relatively shallow aquifer close to the soil surface and can therefore be rather easily contaminated, most commonly by leachates from excreta disposal facilities and animal excrement.

There are many ways of abstracting water from a well, but some methods are so poor that the water is almost certain to become polluted. Only when there is no contact between the person drawing the water and the water in the well, can the system be regarded as having any degree of sanitary protection. An example of a properly protected dug well is shown in Fig. 1.

Fig. 1. Protected dug well

Checklist for dug wells

Is the water-raising system (buckets, ropes, etc.) inaccessible to users, animals, birds, insects, etc., and is it impossible for water drawn from the well to drain back into it?

Is there an impermeable platform preventing entrance of any surface water into the well? (This is particularly important if local flooding may occur.)
2.1.2 Springs

Although spring water normally comes from a protected aquifer, contamination may occur at the point of collection. To prevent the entrance of rainwater into the spring, a channel or ditch should be constructed uphill of the spring about 15 m from the intake. Since periodic cleaning is necessary, an inspection manhole should be provided, as well as a drain at the bottom of the collection chamber. Direct access of humans or animals to the spring should be prevented by means of a protective structure. An example of a properly protected spring is shown in Fig. 2.

Fig. 2. Protected spring

Checklist for springs
Is there a surface-water diversion ditch?
Does the collection chamber have an inspection manhole?
Is there a drainage tube?
Are all openings protected against the entry of animals and direct access by humans?

2.1.3 Drilled wells and boreholes

By drilling a well, it is possible to reach deep aquifers that are far from the soil surface and thus less liable to be affected by contamination. Normally, the groundwater should then be free from microbial pollution and directly
usable as drinking-water. When such a well and associated pump are installed, certain structural precautions should be taken: the pump casing should extend about 30 cm above ground and some 3 m downwards.

Preventive disinfection (chlorination) of the water before it enters the distribution network may be advisable if there is a likelihood of secondary contamination, intermittent supplies, etc. Information on chlorination is given in section 3 of this Annex, p. 56. Fig. 3 shows a cross-section of a protected drilled well.

**Checklist for drilled wells**

Is there an impermeable platform and adequate grouting around the pump casing to prevent the entry of surface water?

Does the well casing extend 30 cm above the platform and is it unbroken?

Is there a casing tube for at least 3 m below ground and is it unbroken?

Does the area surrounding the well drain away from the well?

2.1.4 *Infiltration galleries*

Infiltration galleries are horizontal man-made conduits lying adjacent to a watercourse, river, etc. Such galleries vary in shape and size, ranging from simple perforated tubes to tunnels with an irregular cross-section. The galleries lie at various depths so that direct observation is rarely possible, unless they are very large and have inspection manholes. Any visible part of the system should be inspected. Where possible, the inspection should be made with reference to the original design drawings of the system. Examples of infiltration galleries of the tunnel and tube types are shown in Fig. 4 A and B respectively.
Checklist for infiltration galleries

Does the gallery have an inspection manhole?
Is the manhole protected by a cover and lock?
Is there an impermeable platform to prevent entry of surface water?
Does the casing extend 30 cm above the platform and is it unbroken?
Does the casing extend for at least 3 m below ground and is it unbroken?
Does the area surrounding the pump head drain away effectively?

2.2 Surface-water intake and treatment

As surface waters are, in general, subject rather easily to contamination, they are often treated and disinfected before distribution to the consumers. Two systems are most commonly used, namely:

(a) slow sand filtration; and
(b) coagulation followed by rapid sand filtration.

The essential features of both systems, which must be checked during the sanitary inspection, are described below.

2.2.1 Slow sand filtration

Slow sand filtration is a convenient low-cost method of treating surface water that is not highly polluted. During the treatment process colloidal
particles are retained and organic substances biodegraded. An operational limitation of slow sand filters is that the turbidity of the raw water should not exceed 15 NTU (nephelometric turbidity units). With waters of higher turbidity, plain sedimentation should be applied prior to slow sand filtration (Fig. 5).

The sanitary inspection should include a critical review of the records on filter runs, head loss, periods for filter conditioning, etc. These data should be available from the plant operator. The most important characteristic to be recorded routinely is turbidity. Since the water will not undergo any further treatment other than disinfection, if necessary, the filter effluent should comply with the guideline value for turbidity, which is 5 NTU or 5 JTU (Jackson turbidity units) (see p. 4).

The sanitary inspector should use the equipment available at the plant for checking the turbidity. Alternatively, samples should be taken for examination at a control laboratory. The resulting delay should be recorded since turbidity may change with time.

**Checklist for slow sand filtration**

Is the turbidity of the water flowing into the slow sand filter less than 15 NTU?

Is the turbidity of the water drawn from the slow sand filter less than 5 NTU?

**2.2.2 Coagulation and rapid sand filtration**

Treatment plants of the coagulation and rapid sand filtration type are normally the most complicated available for small-community water supplies. They are capable of treating highly turbid surface water. The turbidity is controlled by the use of added coagulants, flocculation, sedimentation and filtration through a sandbed. A schematic representation of a typical plant is given in Fig. 6.

The coagulants are added by means of a feeder and mixer (disperser) which must be checked for correct and efficient performance. In the flocculator,
large flocs are produced, which settle in the succeeding sedimentation tank. If this sedimentation process is incomplete, problems of overloading will occur in the subsequent filtration. As a rule of thumb, a turbidity of not more than 10 NTU after sedimentation ensures proper filtration.

The complete checking of rapid filters for proper functioning is somewhat complicated and calls for good technical knowledge or extensive training in the use of such equipment. However, a quick and efficient check consists of measuring the turbidity of the water downstream of the filter; it is essential that this finished water should comply with the guideline value of 5 NTU.

The complexity of the treatment steps requires a process control laboratory that can carry out some basic tests. Equipment and facilities should be available for the standard jar test and for certain chemical and physical determinations, e.g., pH and turbidity.

The sanitary inspector should use the on-site laboratory equipment for checking the control of turbidity in the plant. If there is no equipment for measuring turbidity, a sample must be taken for examination by a control laboratory. Samples for bacteriological analysis should also be taken and processed in a control laboratory.

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**Fig. 6. Schematic representation of a coagulation and rapid sand filtration plant**

**Checklist for coagulation and rapid sand filtration**

(a) **Coagulation/sedimentation**

Is the coagulant disperser functioning properly and the coagulant dose controlled correctly?

Will the supply of coagulants last until the next batch arrives?
Is the flocculator operating properly?
Is the turbidity of the water leaving the sedimentation tank less than 10 NTU?

(b) Rapid sand filtration
Is the turbidity of the finished water leaving the filter less than 5 NTU?
Are records kept of the frequency and duration of filter backwashing?

(c) Process control laboratory
Are there facilities at the plant for carrying out the jar test?
Are there instruments at the plant for measuring turbidity?
Are there facilities at the plant for measuring pH?
Are records kept of analyses and tests?

2.3 Rainwater collection and treatment

Treatment of rainwater is not always required and, where necessary, can be simple since the water is normally fairly pure. However, as it flows over the collection surfaces it can become contaminated by dirt, plant debris, bird droppings, etc. Even when the first run-off water carrying dirt has been allowed to run to waste, the collected water may still contain some fine solids.

Slow sand filtration or simple rapid filtration is sufficient to remove such material. Usually the water flows from a storage tank through the filter into the distribution pipe. Alternatively, filtration may be carried out before storage. A schematic flow diagram is given in Fig. 7.

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**Fig. 7. Rainwater treatment scheme**

Checklist for rainwater treatment

Is the water treated by rapid/slow sand filtration?
Is the turbidity of the water drawn from the filter less than 5 NTU?
3. Disinfection

The importance of the disinfection of water supplies in controlling microbial contamination cannot be overemphasized. However good the quality of the water at source, it can become polluted during collection, processing, storage, or distribution. A policy of proper disinfection of water supplies, normally using chlorine, will minimize the risk of waterborne diseases.

Chlorine-releasing products and chlorine itself are the most widely used agents for the disinfection of water supplies. In those places where the water source is not considered safe and protected, an effort must be made to introduce disinfection as soon as possible to minimize health risks. Sanitary inspection should concentrate on the regular use of disinfectants and on whether disinfection is being carried out properly. In particular, a sufficient residual chlorine concentration should be established before the water leaves the waterworks.

Where wells or springs are used as water source, chlorination is carried out in the well or the collection chamber itself, using either equipment on the surface which discharges into the water, or simple equipment situated under water. In the case of drilled wells, chlorination usually takes place in the discharge or intake piping. In rainwater or surface-water systems where slow or rapid filtration is used, chlorination is generally performed after filtration (post-chlorination).

In some cases, chlorine is added as the water enters a water-storage reservoir. Whatever method is used, the chlorine or the chlorine-releasing substance must be in contact with the water for at least 30 minutes. This contact time is defined here as the difference between the time when the chlorine is added and that at which the water arrives at the first consumer in the distribution network.

The sanitary inspector must not only check whether chlorination is carried out, but should also determine if the chlorination is continuous, and whether the dosing equipment is working properly. A check should also be made to establish whether there is a sufficient stock of chlorine-releasing compound to last until the next batch is delivered. In addition, it is necessary to verify whether there is a comparator unit for determining the chlorine concentration, and whether proper records of chlorination are kept. It is recommended that records should be kept on at least a daily basis.

Checklist for chlorination

Is the chlorination being carried out at the time of the inspection?
Is chlorination carried out continuously?
Is the chlorination equipment functioning correctly?
Is the contact time 30 minutes or more?
Is there a sufficient reserve of chlorine or chlorine-releasing substance to last for some time to come?
Is there a means of determining total or residual chlorine in the treated water?
Are daily chlorination records kept?

4. Storage reservoirs

Storage reservoirs (tanks, cisterns) are normally used for storing water to cope with periods of maximum demand on the water-supply system. Such reservoirs can, however, be veritable breeding places for microorganisms if there is no proper protection against external contamination. Consequently, the sanitary inspector should pay special attention to the adequate protection of reservoirs and make sure that access by humans or animals, etc., to the inside is made impossible.

The opening of any overflow, clean-out, or vent pipe should face downwards to prevent the entry of rain, and should be protected by a screen to prevent the entry of birds, insects, rodents, etc. The cover of the reservoir should fit firmly in place, and it should be at an inclined angle to prevent entry of rainwater. There should be an inspection manhole, likewise protected against the entry of humans or animals. These protective measures are illustrated in Fig. 8.

Checklist for storage reservoirs

Does the reservoir have an inspection manhole?
Is the inspection manhole protected by a cover and a lock?
Do the outlets of the vents and overflow pipes face downwards?
Are the vents and overflow pipes protected by grilles?
Is rainwater prevented from entering the reservoir?

5. Distribution networks

The distribution network is defined here as the piping system through which the water is conveyed from the waterworks to the users. There are
unfortunately many ways in which such networks may be polluted and to which the sanitary inspector must therefore pay particular attention. However, this check is perhaps the most difficult of all, since the distribution system is rarely either accessible or visible.

The main causes of pollution during distribution should be reviewed before the sanitary inspection is commenced. Basic guidance on this is given below.

If there are defects in the system, pollutants, including sewage, can infiltrate into it. As long as a positive pressure of water exists in the distribution mains, pollution should not arise; however, a drop in the water pressure will increase the risk of infiltration of potentially polluted water. If suitable instruments are available, it is relatively easy to determine whether there is a significant leak or not. In the great majority of cases, however, these instruments are not available for small-community water-supply systems, especially in rural areas. In these cases the inspector must look for other indications of a leak, e.g., the presence of water or moisture on paving, growth of moss on walls, irregular paving, failure of supply or low pressure in adjacent premises, melting of snow or frost, abnormal fall in residual chlorine levels, complaints by consumers that the water is dirty, anomalous pumping records, etc.

A lack of adequate water pressure can also be detected by checking whether any water flows from taps at various points in the network. In addition, a pressure gauge should be used. Consumers can also give useful information as to whether or not the service is intermittent.

A cross-connection, whether temporary or permanent, can cause pollution of drinking-water. The most common cause of pollution is the use of untreated water from another source to increase the supply. In many waterworks there is a direct main which bypasses the treatment plant, and allows untreated water to enter the system directly; a check should be made for the presence of such cross-connections.

Failure to disinfect distribution systems or parts of such systems after repairs have been carried out is not uncommon. The consequent risk is a potentially serious one, since such systems can be very easily contaminated. A check should be made on the spot by the inspector who is carrying out surveillance at the time of repair. The sanitary inspector should also examine the records kept by the water-supply agency.

The determination of residual chlorine in the water in the distribution system supplements the analyses made in the plant. The residual chlorine analysis, which should always accompany the taking of bacteriological samples, also serves to check whether disinfection is satisfactory and the necessary residual chlorine level maintained.

Back-siphonage means the entry of used (waste) water into the distribution system as a result of a cross-connection and a lack of adequate water-main pressure. Common causes and measures for protecting against back-siphonage are shown in Fig. 9. Such faults can be controlled by proper application of plumbing regulations, which should clearly describe the installation procedures.
Checklist for distribution networks

Is the distribution system free from leaks?

Is pressure maintained continuously throughout the system?

Are cross-connections with poor-quality water absent?

Have any new or repaired mains been disinfected?

Is residual chlorine present at the various points of the system?

Is the system free from back-siphonage problems?

Are there any plumbing regulations related to back-siphonage?

Fig. 9. Protection against back-siphonage: the distance between the outlet and the water level should always be at least twice the diameter of the outlet pipe.

6. Water-supply operators

The personnel responsible for the operation and maintenance of the water-supply system bear a great responsibility for the health of the consumers. Although in small towns it can be difficult to find wholly satisfactory personnel, it is essential that those in charge of the plant and responsible for
operating it have adequate experience and training. The sanitary inspector must therefore take into account the adequacy of training and also the way in which the different operations are carried out. This includes activities such as washing of filters, chlorination, analysis for residual chlorine, cleaning of reservoirs, repair of piping, etc. Ideally, the sanitary inspector, during his visits, should also advise the personnel on the proper performance of the various operations.

**Checklist for water-supply operators**

Is the general professional level of the chief of service:
- University □
- Secondary □
- Primary □
- Other □

Is the level of training of the chief as regards water treatment:
- University □
- Technical college □
- Short course □
- None □

How many years' experience in water treatment has the chief? □□□□ years

How long has the chief been working in the present service? □□□□ years

Is he working full time? Yes □ No □

Is the number of personnel currently employed adequate? Yes □ No □

Is the quality of the personnel currently employed adequate? Yes □ No □

What is the academic level of the head of the laboratory (if applicable)?
- University □
- Secondary □
- Primary □
- Other □

7. Record forms

The sanitary inspector should draw up a form or table so that he can rapidly assess each system and summarize his findings. Such a form should be drawn up on the occasion of the first visit, and then remain unaltered unless changes occur in the supply system, for example, if the type of treatment is modified, or if new sources of water supply are adopted, or if the number and quality of the operators is changed.

The form should include certain checks common to all systems, as well as those which apply specifically to the system inspected. Most of the checks should be of the YES/NO type, and be drafted in such a way that the answer YES signifies the likely absence of problems and health risks. The answer NO suggests potential problems and these can be identified by checking through the record form after the sanitary inspection has been completed. It is suggested that individual record forms be based on the layout and principles illustrated in Fig. 10. The record form should be completed by the sanitary inspector during his visit.
Fig. 10. Comprehensive record form

**ANNEX 2**

**WATER-QUALITY CONTROL PROGRAMME**

(Name of body responsible . . . . . .)

### I General information

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(b) Total water production

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<tr>
<td>08</td>
<td>Daily average</td>
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<td>Annual average</td>
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<td>10</td>
<td>Unknown</td>
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(c) Restrictions in supply during the past year

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<tr>
<td>11</td>
<td>Number of occasions</td>
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<td>12</td>
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### II Sources of water

(a) Groundwater

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<tr>
<td>13</td>
<td>Is the immediate vicinity of the abstraction point (well) free from any potentially polluting sources?</td>
<td>YES</td>
<td>NO</td>
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(b) Surface water

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<td>14</td>
<td>Is the intake correctly sited with respect to pollution outfalls?</td>
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<td>15</td>
<td>Is the intake correctly placed with regard to depth and distance from the bottom?</td>
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<td>16</td>
<td>Is the intake pipe firm and stable in position?</td>
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<td>17</td>
<td>Is the intake system functioning properly?</td>
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(c) Rainwater

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<td>18</td>
<td>Is the rainwater collection surface free from weeds and dirt?</td>
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<td>19</td>
<td>Is there a drain-off system for diverting the first portion of the rain to the waste drain?</td>
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III. Water collection and treatment

(a) Dug wells
20. Is the water-raising system (buckets, ropes, etc.) inaccessible to users, animals, birds, insects, etc., and is it impossible for water drawn from the well to drain back into it? [YES | NO]
21. Is there an impermeable platform preventing entrance of any surface water into the well? (This is particularly important if local flooding may occur) [YES | NO]

(b) Springs
22. Is there a surface-water diversion ditch? [YES | NO]
23. Does the collection chamber have an inspection manhole? [YES | NO]
24. Is there a drainage tube? [YES | NO]
25. Are all openings protected against the entry of animals and direct access by humans? [YES | NO]

(c) Drilled wells
26. Is there an impermeable platform and adequate grouting around the pump casing to prevent the entry of surface water? [YES | NO]
27. Does the well-casing extend 30 cm above the platform and is it unbroken? [YES | NO]
28. Is there a casing tube for at least 3 m below ground and is it unbroken? [YES | NO]
29. Does the area surrounding the well drain away from the well? [YES | NO]

(d) Infiltration galleries
30. Does the gallery have an inspection manhole? [YES | NO]
31. Is the manhole protected by a cover and lock? [YES | NO]
32. Is there an impermeable platform to prevent entry of surface water? [YES | NO]
33. Does the casing extend 30 cm above the platform and is it unbroken? [YES | NO]
34. Does the casing extend for at least 3 m below ground and is it unbroken? [YES | NO]
35. Does the area surrounding the pump head drain away effectively? [YES | NO]

(e) Slow sand filtration?
36. Is the turbidity of the water flowing into the slow sand filter less than 15 NTU? [YES | NO]
37. Is the turbidity of the water drawn from the slow sand filter less than 5 NTU? [YES | NO]

(f) Coagulation/sedimentation
38. Is the coagulant disperser functioning properly and the coagulant dose controlled correctly? [YES | NO]
39. Will the supply of coagulants last until the next batch arrives? [YES | NO]
40. Is the flocculator operating properly? [YES | NO]
41. Is the turbidity of the water leaving the sedimentation tank less than 10 NTU? [YES | NO]

(g) Rapid sand filtration
42. Is the turbidity of the finished water leaving the filter less than 5 NTU? [YES | NO]
43. Are records kept of the frequency and duration of filter backwashing? [YES | NO]
Fig. 10 (continued)

(h) Process control laboratory
44. Are there facilities at the plant for carrying out the jar test?
45. Are there instruments at the plant for measuring turbidity?
46. Are there facilities at the plant for measuring pH?
47. Are records of analyses and tests kept?

(i) Rainwater treatment
48. Is the water treated by rapid/slow sand filtration?
49. Is the turbidity of the water drawn from the filter less than 5 NTU?

IV. Disinfection
50. Is the chlorination being carried out at the time of the inspection?
51. Is chlorination carried out continuously?
52. Is the chlorination equipment functioning correctly?
53. Is the contact time 30 minutes or more?
54. Is there a sufficient reserve of chlorine or chlorine-releasing substance to last for some time to come?
55. Is there a means of determining total or residual chlorine in the treated water?
56. Are daily chlorination records kept?

V. Storage reservoirs
57. Does the reservoir have an inspection manhole?
58. Is the inspection manhole protected by a cover and a lock?
59. Do the outlets of the vents and overflow pipes face downwards?
60. Are the vents and overflow pipes protected by grilles?
61. Is rainwater prevented from entering the reservoir?

VI. Distribution network
62. Is the distribution system free from leaks?
63. Is pressure maintained continuously throughout the system?
64. Are cross-connections with poor-quality water absent?
65. Have any new or repaired mains been disinfected?
66. Is residual chlorine present at the various points of the system?
67. Is the system free from back-siphonage problems?
68. Are there any plumbing regulations related to back-siphonage?

VII Water-supply operators
69. Is the general professional level of the chief of service

University □ Secondary □ Primary □ Other ..
GUIDELINES FOR DRINKING-WATER QUALITY

Fig. 10 (continued)

70. Is the level of training of the chef as regards water treatment:
   University ☐  Technical College ☐  Short course ☐  None ☐

71. How many years' experience in water treatment has the chef? _______ years

72. How long has the chef been working in the present service? _______ years

73. Is he working full time? Yes ☐  No ☐

74. Is the number of the personnel currently employed adequate? Yes ☐  No ☐

75. Is the quality of the personnel currently employed adequate? Yes ☐  No ☐

76. What is the academic level of the head of the laboratory (if applicable)?
   University ☐  Secondary ☐  Primary ☐  Other ☐

VIII. Consumers' observations

77. Major complaints and comments were
   (i) ..................................................
   (ii) ..................................................
   (iii) ..................................................

IX. Corrective measures

78. Mandatory correction of deficiencies in priority order.
   (i) ..................................................
   (ii) ..................................................
   (iii) ..................................................

79. Suggested improvements
   (i) ..................................................
   (ii) ..................................................
   (iii) ..................................................

X. Relation to previous inspection

80. Date of previous inspection Day ☐  Month ☐  Year ☐

81. Have the proposed corrective measures been carried out in the meantime? Yes ☐  No ☐

82. Which corrective measures were not carried out?
   (i) ..................................................
   (ii) ..................................................
   (iii) ..................................................

XI. Completion of this inspection

83. Date of inspection Day ☐  Month ☐  Year ☐

84. Name of inspector ..........................................

85. Name of supervisor ..........................................

86. Remarks:
   (i) ..................................................
   (ii) ..................................................
   (iii) ..................................................
The preparation of specific record forms for each water-supply system can best be illustrated by an example. To this end a case is presented, which is intentionally complicated, relating to a fairly large rural community water supply where the water is derived from three different sources: a river, a spring, and a drilled well.

The river water is treated by means of a slow sand filter (without prior sedimentation); the treated water then passes on to a storage reservoir which feeds into the distribution system. The water from the spring is also stored in a reservoir and then fed into the distribution system. The water from the drilled well, on the other hand, is pumped directly into the system. Equipment is available for chlorinating the water derived from the river and the spring; water from the drilled well is pumped into the system without chlorination.

The service has a chief and one operator under his supervision. There is no laboratory.

The flow scheme of this supply system is presented in Fig. 11. The relevant questions for the sanitary inspection, selected from the comprehensive record form (Fig. 10), are identified by number in Fig. 12.

Fig. 11. Example of community supply system
Fig. 12. Example of individual record form for community supply system illustrated in Fig. 11 (the numbers refer to the questions in the comprehensive record form, Fig. 10)

A. General information (Section I)
   Questions 01–12

B. Sources of water and treatment (Sections II–V)
   (a) River water intake
       Questions 14–17, 36–37, 50–56, 57–61
   (b) Spring water collection
       Questions 13, 22–25, 50–56, 57–61
   (c) Drilled well
       Questions 13, 26–29 (Note: No chlorination)

C. Distribution network (Section VI)
   Questions 62–68

D. Water-supply operators (Section VII)
   Questions 69–75

E. Consumers' observations (Section VIII)
   Question 77

F. Corrective measures (Section IX)
   Questions 78–79

G. Relation to previous inspection (Section X)
   Questions 80–82

H. Completion of this inspection (Section XI)
   Questions 83–86
ANNEX 3

COLLECTING WATER SAMPLES FOR MICROBIOLOGICAL EXAMINATION

Although it may seem a simple matter to collect a sample of water, errors can occur, and special care is therefore needed; problems can also arise independently of the sampling technique used. Unless valid samples are collected, the careful work that is carried out in the subsequent analysis could be a complete waste of time.

Water can be divided into three basic types for the purposes of sampling:

1. water from a tap in a distribution system, or from a fixed hand pump, etc;
2. water from a watercourse or reservoir (river, lake, tank);
3. water from a dug well, etc., where sampling is more difficult than from an open water source.

1. Sampling from a tap or pump outlet

The steps to be followed in sampling from a tap or pump outlet are described in sequence below.

A. Clean the tap

Remove from the tap any attachments that may cause splashing and, using a clean cloth, wipe the outlet in order to remove any dirt.
B. Open the tap

Turn on the tap at maximum flow rate and let the water flow for 1–2 minutes.

C. Sterilize the tap

Sterilize the tap for a minute with the flame from an ignited cotton-wool swab soaked in alcohol; alternatively, a gas burner or cigarette lighter may be used.

D. Open the tap prior to sampling

Carefully turn on the tap and allow the water to flow for 1–2 minutes at a medium flow rate.
E. Open a sterilized bottle

(a) Standard technique:
Untie the string fixing the protective brown paper cover and pull out or unscrew the stopper.

(b) Machine-capping technique:
Untie the string attached to the protective brown paper cover and remove, while an assistant opens the packet containing the sterile cap.
F. Fill the bottle

While holding the cap and protective cover face downwards (so as to prevent entry of dust that might carry microorganisms), immediately hold the bottle under the water jet, and fill.

A small air space should be left to facilitate shaking at the time of inoculation prior to analysis.

G. Stopper or cap the bottle

(a) Standard technique:
Place the stopper in the bottle or screw on the cap and fix the brown paper protective cap in place with the string.
(b) Machine-capping technique: Place the cap in position and then affix using the capping machine; attach the protective brown cover by means of the string.
2. Sampling from a watercourse or reservoir
Open the sterilized bottle by the techniques described in section 1, p. 69.

A. Fill the bottle
Holding the bottle by the lower part, submerge it to a depth of about 20 cm, with the mouth facing slightly upwards; if there is a current, the bottle mouth should face towards the current.

The bottle should then be stoppered or capped as described previously (p. 70).

3. Sampling from dug wells and similar sources
A. Prepare the bottle
With a piece of string, attach a stone of suitable size to the sampling bottle.
B. Attach bottle to string
Take a 20-m length of clean string rolled around a stick and tie on to the bottle string. Open the bottle as described in section 1 (p. 69).

C. Lower the bottle
Lower the bottle, weighted down by the stone, into the well, unwinding the string slowly. Do not allow the bottle to touch the sides of the well.

D. Fill the bottle
Immerse the bottle completely in the water and lower it down to the bottom of the well.
E. Raise the bottle

Once the bottle is judged to be filled, rewind the string round the stick to bring up the bottle. If the bottle is completely full, discard some water to provide an air space.

Stopper or cap the bottle as described previously (p. 70).
ANNEX 4

FIELD TESTS FOR BACTERIOLOGICAL ANALYSIS

Bacteriological analysis should preferably be carried out in a laboratory equipped with at least the basic facilities. If the samples cannot be processed in a laboratory within 24 hours or so (which may be the case in remote areas or villages), portable equipment installed in a health centre, a school, or similar building should be used. Such field investigations are appropriate when drinking-water surveys lasting several days are carried out in districts lacking proper microbiological laboratories, or where electricity supplies are inadequate. Because there are often difficulties with transportation in remote areas, the amount of laboratory equipment will have to be kept to a minimum. This can limit the number of water-quality parameters that can be measured. In the case of unchlorinated water supplies, only faecal coliforms normally need to be measured. Total and faecal coliform measurements should, however, be considered for chlorinated water sources, together with the determination of residual chlorine. For the analysis, either the multiple-tube (MT) method or the membrane-filter (MF) method may be used.

The bacteriological examination should always be carried out in combination with a sanitary inspection. The bacteriological results obtained under these circumstances can then serve as a verification of the results of the sanitary inspection, and will aid in defining priorities for remedial action.

1. Basic laboratory equipment

In remote areas, where bacteriological analyses are carried out rather infrequently, it is advisable to set up a small laboratory containing the basic equipment in a convenient village within the study area.

Normally, presterilized media and other materials should be brought from a regional laboratory, rather than prepared locally. However, if local facilities are adequate, materials and equipment for making the media, such as a pressure cooker, a heating plate, and preweighed portions of dehydrated media, should be obtained.

1.1 Multiple-tube method

The following basic equipment is required for the multiple-tube method:

(a) a small water-bath in which the temperature can be set at 35 or 37 ± 0.5 °C and 44 ± 0.5 °C;
(b) presterilized tubes of double- and single-strength media of chosen composition, and containing Durham tubes;
(c) test-tube racks;
(d) presterilized pipettes;
(e) sterile sampling bottles.

1.2 Membrane-filter method

The following basic equipment is required:
(a) a small water-bath or incubator in which the temperature can be set at 35 or 37 ±0.5°C and 44 ±0.5°C;
(b) a membrane-filtration unit;
(c) sterile membrane filters;
(d) sterile Petri dishes with absorbent pads;
(e) ampoules of media or bottles with presterilized broth of chosen composition;
(f) gas-burner or ethanol for flaming;
(g) presterilized pipettes and forceps;
(h) water-tight plastic bags (if a water-bath is used);
(i) sterile sampling bottles.

2. Field testing methods

For field investigations, carried out in areas where electricity is lacking or is only available periodically, an alternative methodology has to be adopted in performing the bacteriological analysis. The following alternatives are available:
(a) delayed-incubation method;
(b) MT method for faecal coliforms, field modification (see Annex 5);
(c) MF method, field modification (see Annex 6).

2.1 Delayed-incubation method

2.1.1 Principle

When the distance between the place of sampling and the laboratory is too great to allow the processing of samples in the laboratory within 24 hours of collection, and where a field incubator is not available, delayed incubation may be used. In this procedure, the sample is filtered in the field and the filter placed on a pad saturated with a holding medium (transportation medium); this keeps the bacteria viable, and will arrest visible growth for up to 72 hours. If placed in sturdy containers, or in a suitably padded envelope, the filters may be sent to the laboratory by mail or by other means of transport. Extremes of heat and cold should be avoided during transport; if high temperatures are encountered, some visible growth may occur on the holding medium.

Holding media are available for both total coliforms and faecal coliforms. Examples are the LES MF holding medium for total (and faecal) coliforms and the M-VFC holding medium for faecal coliforms. It has been shown that
the total coliform holding media can also be used for faecal coliforms; however, it should be noted that slight changes in the colour of the coliform colonies will be observed if this procedure is adopted.

2.1.2 Equipment and materials

The following equipment and materials are required:

(a) field filtration unit (for sterilization requirements, see Annex 6);
(b) suction syringe;
(c) Petri dishes with tight-fitting lids, and absorbent pads;
(d) preprepared sterile holding media;
(e) presterilized pipettes;
(f) sterile forceps;
(g) gas-burner or ethanol for flaming;
(h) sterile sampling bottles (not needed if sterilizable sampling cup is available).

2.1.3 Procedure

A. Pipette the sterile holding medium into a Petri dish containing a sterile absorption pad. Wait until the pad is thoroughly soaked and decant any excess medium from the dish.

B. Filter 100 ml of water sample through a sterile membrane filter in the sterilized filtration unit.
C. Disconnect the filtration unit and, using the forceps, place the membrane filter (grid side up) on the pre-soaked absorption pad in the Petri dish. Ensure that no air bubbles are trapped between the pad and the filter. Store the Petri dish in a suitable container for transportation to the laboratory (this should take not longer than 72 hours). If it is sent by mail, the Petri dish should be packed in a suitably padded envelope.

D. Upon arrival in the laboratory, transfer the membrane to LES Endomedium for total coliforms, or MFC medium for faecal coliforms, and proceed as described in the MF method (see Annex 6).

2.2 Multiple-tube method

The technique is essentially that used in the laboratory procedure for total and faecal coliforms as described in Annex 5. If only faecal coliforms are to be determined, the alternative method given for this case in Annex 5 can be used.

An electric thermostatically-controlled water-bath, connected to a battery or an automobile cigarette-lighter socket, can be used for field incubation. "Dry-bath" aluminium block incubators are also available for small-scale investigations. Screw-cap tubes with double- and single-strength media are suitable for transportation in the field.
2.3 Membrane-filter method

2.3.1 Principle

The technique is essentially that used in the laboratory procedure described in Annex 6, the only difference being that the equipment is portable. The required vacuum can be produced by means of a special syringe or suitable hand-pump. Several types of portable equipment are produced by various manufacturers.

2.3.2 Equipment

The essential items of field equipment are shown in Fig. 1.

Fig. 1. Field equipment for MF method:
(a) incubator; (b) rack for incubation of Petri dishes; (c) filter funnel, 100-ml capacity; (d) porous support for filter; (e) filter support; (f) suction vessel; (g) syringe with two-way valve for providing the vacuum needed for the filtration; (h) sample vessel; (i) forceps; (j) bottle containing alcohol; (k) bottle containing sterile buffer; (l) plastic Petri dishes; (m) pipettes.
Certain items call for detailed comment, as follows:

(a) **Incubator.** A suitable portable incubator or water-bath is needed so that the temperature can be preset; some units of this type can be connected to 6, 12, or 24 volts DC, or 115 or 230 volts AC supply. It is possible to operate them from a battery, an automobile cigarette-lighter socket, or a normal wall outlet (using suitable adaptors). Portable incubators, although expensive, are well suited for field measurements of total and faecal coliforms.

(b) **Filtration units.** Several specially designed filtration systems are available, ranging from simple field monitors and syringes, to polycarbonate plastic vacuum systems fitted with syringes, to complete stainless-steel systems. The simple field monitors are difficult to use, however, and in some instances have given poor recovery of coliform bacteria. The funnels used in the field filtration units can be sterilized between filtrations by immersing them in boiling water for 5 minutes (longer at high altitudes). The stainless-steel units can be flamed with burning alcohol or by means of a gas-burner. Some units are provided with a ring in the funnel base, which can be soaked with methanol and ignited; after the methanol has been allowed to burn for a few seconds, the unit can be sealed off by placing the stainless-steel flask over the funnel and base. This results in incomplete combustion of the methanol, thereby forming formaldehyde which has a sterilizing effect. The unit should be kept sealed for 15 minutes to ensure that it is completely sterilized.

(c) **Culture media.** Various suppliers provide sterilized culture media in ready-to-use ampoules. Alternatively, preprepared sterile broth of chosen composition or preprepared agar plates can be used; it is then important to ensure that the shelf life is long enough for the intended field trip.
2.3.3 Determination of total and faecal coliforms

The procedures for the determination of total and faecal coliforms are essentially the same; only the culture media employed and the incubation temperature are different. The steps in the procedure are as follows:

A. Sterilize the filtration unit.

B. If broth medium is used, add an ampoule of culture medium (or enough broth from a suitable container) to an absorbent pad in a sterile Petri dish; it is important to ensure that the pad is completely soaked.
C. Pour a known volume of the sample through the filter funnel; filtration is carried out by applying a vacuum by means of a hand-pump or syringe.

D. Rinse the funnel with two portions of 20–30 ml of buffer (for information on the buffer, see Annex 6).

E. Disconnect the funnel and transfer the filter with the sterile forceps to the soaked pad (or agar plate); the grid side should be uppermost and a rolling motion should be used to prevent trapping of any air bubbles.
F. Place the Petri dish in the incubator; if a water-bath is used, the dish should be placed in a heavy or specially weighted container and immersed in water and each dish should be sealed first with water-proof tape. For total coliforms, the incubation time should be 18-24 hours at 35 or 37°C. For faecal coliforms a temperature of 44 ±0.5°C is needed.

The detection, counting and calculation of the bacteria is carried out in exactly the same way as in the MF laboratory technique (see Annex 6).

2.4 Simple screening methods

A number of simple screening methods are available for use under certain circumstances, namely the surface spread plate, MF-absorption pad-filtration, and dip counter methods, but are not recommended here since the results they provide are not compatible with the specified WHO guideline values for the bacteriological quality of water supplies.
Annex 5

MULTIPLE-TUBE METHOD

1. Principle

In the multiple-tube (MT) method, a series of tubes containing a suitable broth culture medium is inoculated with test portions of a water sample. After a specified incubation time at a given temperature, each tube showing gas formation is regarded as "presumptive positive" since this indicates the possible presence of coliforms; however, since gas may also be produced by other organisms, a subsequent confirmation test is advisable. The two tests are known respectively as the presumptive and confirmed tests.

For the confirmed test, a more selective culture medium is inoculated with material taken from the positive tubes. After an appropriate time interval, the tubes are examined for gas formation as before. The concentration of bacteria in the sample can then be estimated from the number of tubes inoculated, and the number of positive tubes obtained in the confirmed test. The most probable number (MPN) of bacteria present can be estimated using specially devised statistical tables. This technique is known as the MPN method.

Fig. 1 shows the procedures involved in the bacteriological analysis of a water sample, together with the appropriate incubation times and temperatures. Different dilutions of the test sample are required, according to the type of water being analysed.

2. Inoculation

Different test portions to provide tenfold serial dilution steps may be used, the dilutions being based on the anticipated numbers of coliform bacteria in the water sample being tested. The reliability of the result obtained depends on the number of tubes inoculated with each test portion. In certain instances this number can be reduced to three in each dilution step. Each combination of inoculated tubes will have its own table of MPN values.

2.1 Unpolluted water

Water entering or in the distribution system may generally be assumed to contain little or no pollution. In this case, only five 10-ml volumes of water sample need to be inoculated into five tubes; each tube should contain 10 ml of double-strength medium.
Fig. 1. Diagram showing procedures involved in presumptive and confirmed multiple-tube tests

Water sample

24 h at 35°C or 37°C

No gas

Reincubate for 24 h at 35°C or 37°C

No gas

NEGATIVE FOR COLIFORMS

Gas

Positive presumptive test for coliforms

Confirmed test

48 h at 35°C or 37°C

No gas

NEGATIVE FOR COLIFORMS

Gas

POSITIVE FOR COLIFORMS

24 h at 44°C

No gas

NEGATIVE FOR FAECAL COLIFORMS

Gas

POSITIVE FOR FAECAL COLIFORMS
2.2 Polluted water

Water suspected to be more contaminated, e.g., untreated water from certain raw water sources, will need to be examined using different inoculation volumes in tenfold dilution steps. The following inoculations are normally made:

(a) 10 ml of sample to each of five tubes containing 10 ml of double-strength medium;
(b) 1.0 ml of sample to each of five tubes containing 10 ml of single-strength medium;
(c) 1.0 ml of a 1:10 dilution of sample (i.e., 0.1 ml of sample) to each of five tubes containing 10 ml of single-strength medium.

If the sample is expected to be highly contaminated, aliquots of 1.0 ml of tenfold serial dilutions from each dilution step are inoculated into five tubes containing 10 ml of single-strength medium.

If the work-load is very heavy and the time available is limited, the number of tubes can be reduced to three in each series. However, inoculation of five tubes with each sample volume gives an MPN result that is statistically more reliable than that obtained by inoculation of only three tubes.

3. Equipment

The following basic laboratory equipment is necessary:

(a) Hot-air oven. This should be sufficiently large to take easily all the pipettes, test-tubes, sample bottles, and other glassware and apparatus that needs to be sterilized by dry heat. Free circulation of the hot air inside the oven is essential for proper sterilization. The oven temperature should be controlled at 170°C; a thermometer should be used to check the temperature. The sterilization time required is one hour.

(b) Autoclave. This should be sufficiently large to permit free flow of steam around the normal load to be sterilized. It should be fitted with a manometer and thermometer, the greater part of the thermometer being situated in the outlet of the autoclave (this minimizes the chances of breaking the thermometer). The autoclave should be operated strictly in accordance with the manufacturer’s instructions; this should ensure that all the air in the chamber can be replaced by steam. Sterilization should be achieved in not more than 30 minutes. The recommended sterilization temperatures and times for different types of culture media should be strictly adhered to.

(c) Incubator. This must be fitted with a temperature control and should be capable of maintaining a uniform temperature correct to ±0.5°C. The interior should be sufficiently large to permit free flow of air when the incubator is full. Thermometers should be placed at representative points in the incubator, and temperature should be monitored periodically (preferably daily).

(d) Water-bath. This should be fitted with a thermostat so that a uniform temperature of 44±0.5°C can be maintained for culturing faecal coliforms. It should be fitted with stainless-steel racks and be electrically heated.
(e) **pH meter.** This is needed to check the pH of the media.

(f) **Balance.** This is needed for weighing powdered culture medium and the chemicals used to prepare solutions. Most of the weighings are in the range 1–100 g. The balance should have an accuracy of ±1 g at a 150-g load.

(g) **Water distillation apparatus or water deionizer.** This is required to produce non-toxic water, i.e., water free from any substances that can interfere with bacterial growth.

(h) **Dilution bottles.** Bottles with screw caps free from soluble toxic substances are excellent for this purpose. These should be large enough to allow sufficient air space above the liquid so that good mixing occurs on shaking. The volume depends on the preferred dilution ratio. If a dilution ratio of 1:10 is preferred, bottles with 9 ml (for reception of 1-ml aliquots of sample) or 90 ml (for reception of 10-ml aliquots of sample) of diluent solution are usually used; they should be large enough to maintain these volumes after sterilization for 20 min at 121°C.

(i) **Pipettes.** Two sizes of pipette (1 and 10 ml) with cotton plugs at the mouthpiece are required. The 1-ml pipettes should be graduated in 0.1-ml increments. Pipettes with chipped or broken tips should be discarded. Pipettes are conveniently stored in a sterilizable metal container. A separate container should be employed for each size of pipette. Pipettes may also be wrapped individually in paper, and heat-sterilized.

(j) **Media preparation equipment.** Glass or stainless-steel containers are required. Any heating equipment and stirrers used in the preparation of media should be clean and free from soluble toxic materials.

(k) **Gas burner.** The Bunsen or similar type is adequate.

(l) **Culture tubes containing inverted vials (Durham tubes).** The tubes and vials should be of such a size that the vial can be filled completely with medium, and submerged in the tube.

(m) **Test-tube racks.** The openings should be large enough to take the largest diameter culture tubes used.

(n) **Inoculation loop and holder.** Lengths of 24- or 26-gauge wire (7.5–10 cm) should be used. Nichrome wire is acceptable, but platinum-iridium is better. The wire lengths (loops) are set in handles made of metal or glass of diameter similar to that of a pencil. To form the inoculation loop, the wire is bent to form a circle 3–4 mm in diameter.

(o) **General laboratory equipment.** Various round and Erlenmeyer flasks, beakers, stands, etc., are required.

### 4. Culture media and dilution water

Commercially available dehydrated media simplify the preparation of culture broths, and are therefore recommended for laboratory work. Various manufacturers produce these media as powders, which can then be easily weighed out, dissolved in distilled water, and dispensed into culture tubes prior to sterilization.
Several different culture media are available for the presumptive test, for example:
—lauryl tryptose broth (LTB);
—MacConkey broth;
—lactose broth.

These three media are in common use in many countries. The selectivity of MacConkey broth and LTB depends respectively on the presence of bile salts and the surface-active agent, lauryl sulfate; lactose broth is a non-selective medium.

As a confirmatory medium for total coliforms brilliant green lactose bile broth (BGB) is most widely used.

To confirm the presence of faecal coliforms, either BGB broth or *Escherichia coli* (EC) broth is used.

### 4.1 Preparation of media

Media should be prepared in accordance with the manufacturer's instructions, as follows:

(a) Dissolve the stated amount of the dehydrated medium in distilled water to obtain the double-strength or single-strength presumptive medium (for confirmatory analysis, only single-strength medium is used).

(b) Dispense the requisite volume into culture tubes containing an inverted Durham tube, and cap the culture tubes.

(c) Sterilize in an autoclave or pressure cooker at 114°C for 10 minutes (or in accordance with the manufacturer's specifications). It is particularly important that media containing disaccharides, e.g., lactose, are not autoclaved at higher temperatures.

(d) The sterilized medium should be stored at room temperature (approximately 25°C), to maintain sterility. In addition, since several dyes are light-sensitive, the solution should be protected from exposure to light.

### 4.2 Preparation of dilution water

A special buffered, sterilized water is used to prepare sample dilutions for inoculation into the culture medium. The water is prepared from a concentrated stock solution of phosphate buffer. To make the stock solution, dissolve 34.0 g of potassium dihydrogen phosphate (KH$_2$PO$_4$) in 500 ml of distilled water. This solution should have a pH of 7.2 (this should be checked with a pH-meter). The pH can be increased if necessary by adding a few drops of 1 mol/litre sodium hydroxide solution (4.0 g dissolved in 100 ml of distilled water). Then add sufficient distilled water to make up to 1 litre. When the stock solution is not in use it should be stored in a tightly closed bottle at 4–10°C, to retard microbial growth.

When using the dilution water, add 1.25 ml of stock solution to 1 litre of distilled water and dispense into bottles for sterilization in the autoclave. Before sterilization, loosen the stoppers of the bottles. Sterilize for 20 minutes at 121°C. After sterilization, tighten the stoppers and store the dilution water in a clean place until needed.
An alternative dilution water can be prepared by the addition of magnesium chloride and has been shown to give a slightly higher recovery rate. A sterile 0.1% solution of peptone in distilled water (final pH 6.8) may also be used as an alternative. Finally, sterile physiological saline (9 g of sodium chloride per litre) is widely used in health centres for dilution purposes.

5. Application to unpolluted water

5.1 Procedure

The procedure to be used for testing relatively unpolluted water, such as treated water from waterworks, is shown below.

A. Remove the paper wrapping from the sample bottle.

B. With the stopper in position, shake the bottle vigorously to achieve a homogeneous dispersion of bacteria. (If the bottle is completely full of water, remove the stopper and discard about 20–30 ml of water; then replace the stopper and shake. This ensures thorough mixing.)
C. With a sterile 10-ml pipette, inoculate 10 ml of the sample into each of five tubes containing 10 ml of presumptive broth (double strength). It is advisable to shake the tubes gently to distribute the sample uniformly throughout the medium.

D. Incubate the tubes at 35°C or 37°C for 24 hours.
E. At the end of the 24-hour incubation period, observe each tube for the presence of gas. Gas, if present, can be seen in the Durham tube; if none is visible, gently shake the tube. If any effervescence (streams of tiny bubbles) is observed, the tube should be considered positive.

F. Enter the number of positive tubes after 24 hours in a table.

G. Reincubate negative tubes for a further 24-hour period. At the end of this period, check the tubes again for gas production as in E above. Gas production at the end of either 24 or 48 hours incubation is presumed to be due to the presence of coliforms in the sample.
H. Enter the number of positive tubes after 48 hours in the table.

I. The confirmed test should be carried out at the end of both the 24-hour and the 48-hour incubation. Using a loop, transfer one or two drops from each presumptive positive tube to a corresponding sterile confirmative 10-ml tube containing, e.g., BGB broth. Before each transfer, sterilize the inoculation loop by flaming and allow to cool.

J. If the presence of faecal coliforms is also to be investigated, subcultures in two tubes containing confirmative broth (e.g., BGB broth) should be prepared from each presumptive positive tube. EC medium is preferred in some areas for confirmation of faecal coliforms.
K. To confirm the presence of coliforms, incubate one subculture tube from each presumptive positive tube for 48 hours at $35^\circ C$ or $37^\circ C$.

L. Check the tubes at the end of the 48-hour incubation period; the presence of gas confirms that coliforms are present in the sample. Enter the results in the table.

M. To confirm the presence of faecal coliforms incubate a second subculture tube from each presumptive positive tube for 24 hours at $44 \pm 0.5^\circ C$. 

N. If, at the end of 24 hours' incubation, gas is present in the tubes, the presence of faecal coliforms is confirmed.

5.2 Determination of MPN

For treated water, where five 10-ml portions are inoculated, the MPN can be found from the test results by means of Table 1.

<table>
<thead>
<tr>
<th>Number of tubes giving positive reaction out of 5 of 10 ml each</th>
<th>MPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>2</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>9.2</td>
</tr>
<tr>
<td>4</td>
<td>16.0</td>
</tr>
<tr>
<td>5</td>
<td>Indeterminate</td>
</tr>
</tbody>
</table>

An example is given in Fig. 2 to show how the test results are interpreted. It will be seen that three confirmed positive tubes have been obtained for the total coliform group. From Table 1, the corresponding value of the MPN can be seen to be 9.2 total coliforms per 100-ml sample. As regards the test for faecal coliforms, there was only one confirmed positive tube. Consequently, the value of the MPN for this group is 2.2 per 100 ml.
Fig. 2. Example of determination of total coliforms and faecal coliforms

A. PRESumptive TEST

Inoculate 10 ml of sample into each of 5 tubes containing presumptive broth. Incubate for 24 h at 35°C or 37°C.

B. CONFIRMED TEST FOR TOTAL COLIFORMS AND FAECAL COLIFORMS

Inoculate two tubes of broth (e.g., BGB broth) from each positive presumptive tube.

Incubate for 48 h at 35°C or 37°C.

Inoculate 10 ml of sample into each of 5 tubes containing presumptive broth. Incubate for 24 h at 35°C or 37°C.

- GAS: positive presumptive test
- NO GAS: incubate for another 24 h (total incubation time: 48 h)

- GAS: positive presumptive test
- NO GAS: coliforms absent

- GAS: faecal coliform positive
- NO GAS: faecal coliform negative

WHO 85353
6. Application to polluted water (full method)

6.1 Procedure

The procedure to be used for the testing of water that is expected to be polluted, even though it may have been treated, is shown below and is essentially similar to that described in section 5.1, with the exception that several dilutions are used.

A. Arrange three rows of five tubes each in a test-tube rack. The tubes in the first row (F1) hold 10 ml of double-strength presumptive medium while the tubes in the second and third rows (F2, F3) contain 10 ml of single-strength presumptive medium.
B. With a sterile pipette add 10 ml of sample to each of the five tubes in row F1.

C. With a sterile pipette, add 1 ml of sample to each of the five tubes in row F2.
D. Prepare a 1:10 dilution of the sample by adding 1 ml of sample to 9 ml of dilution water (use a 1-ml sterile pipette). Recap the bottle containing the diluted sample and shake it vigorously.

E. With another sterile pipette add 1 ml of the 1:10 dilution to each of the five tubes in row F3.
F. After gently shaking the tubes to mix the inoculum, incubate the rack with the 15 tubes at 35°C or 37°C for 24 hours. Then proceed in the same way as for unpolluted water, starting from 5.1E, page 91.

6.2 Determination of MPN

The MPN is found in a similar way to that described in section 5.2 but, because of the large number of tubes, the more complicated Table 2 must be used.

The following example shows how the results are obtained.

Suppose that, after confirmation of the presence of total coliforms, the following results are obtained:

- 5 positive tubes in row F1 (sample volume inoculated, 10 ml);
- 3 positive tubes in row F2 (sample volume inoculated, 1 ml);
- 1 positive tube in row F3 (sample volume inoculated, 0.1 ml).

The results can thus be coded as 5–3–1; they represent the confirmed test for coliforms. Table 2 indicates that a coded result of 5–3–1 (5 × 10 ml positive, 3 × 1 ml positive, 1 × 0.1 ml positive) gives an MPN value of 110, i.e., the water sample contains an estimated 110 coliforms per 100 ml.

The confirmed test for faecal coliforms is carried out by transferring a loopful from each of the positive presumptive test-tubes into confirmatory media, and incubating at 44 ± 0.5°C for 24 hours. Let us suppose that this test gives a coded result of 4–3–0. Table 2 then gives an MPN value of 27, i.e., 27 faecal coliforms per 100 ml of sample.

Next, let us consider an example of heavily polluted water. The procedure outlined above may give a coded result of 5–5–5. Such a result does not give a definite MPN value. When such heavy contamination is suspected it is usual to inoculate more than three dilutions in a series of factors of ten. This series of tenfold dilutions should be made in such a way that a negative result is likely for at least the highest dilution inoculated. If 5 × 1.0 ml, 5 × 0.1 ml, 5 × 0.01 ml and 5 × 0.001 ml are initially inoculated and a confirmed coded...
result of 5–5–4–1 is obtained, only three of these results should then be used to obtain the MPN value from Table 2. These should be selected by taking the smallest sample volume (in this case 0.1 ml) in which all the tubes give a positive result, and the two next succeeding higher dilutions. The coded result of these three volumes is then used to obtain the MPN value from Table 2. In the above example, the result 5–4–1 would be chosen, representing volumes of 0.1, 0.01 and 0.001 ml of the sample. The MPN value obtained from Table 2 should be multiplied by 100 to obtain the MPN for this particular sample (see below); in this case the result is 17 000 per 100 ml.

On occasions, the laboratory worker may find it difficult to determine the multiplying factor to be used to obtain the appropriate MPN for the sample tested. A simple way to determine the MPN is to divide the MPN value obtained from Table 2 by the sample volume represented by the middle
number in the chosen code. For example, consider a chosen code of 5–2–0, in which the 2 represents a sample volume of 0.01 ml (see Table 3). From Table 2 the MPN for a code of 5–2–0 is 49. The MPN value for the sample tested will therefore be:

$$\frac{49}{0.01} = 49 \times 100 = 4900$$

Examples are given in Table 3 of the factors to be used to multiply the MPN value found from Table 2 in order to obtain the appropriate MPN for different dilutions.

Table 3. Examples of multiplying factors for determination of the MPN for different dilutions of sample

<table>
<thead>
<tr>
<th>Example</th>
<th>Number of tubes giving positive reaction out of</th>
<th>Coded result chosen</th>
<th>Multiplying factor for MPN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 of 1 ml each</td>
<td>5 of 0.1 ml each</td>
<td>5 of 0.01 ml each</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

7. Application to polluted water ("shorter" method)

The procedure for the shorter method is virtually identical to that described in section 6.1, the only difference being that, instead of five tubes of each sample volume, only three are inoculated. This necessitates the use of a different table (Table 4) for determining the MPN.

8. Selection of tubes for confirmed test

Any bacteriological analysis should always include the confirmed test. If only five 10-ml portions are tested, the confirmed test for coliforms and faecal coliforms must be carried out on all tubes showing gas production. However, if the inoculation involved five (or three\(^a\)) tubes for each of more than three sample volumes (e.g., 10, 1.0, 0.1, 0.01 and 0.001 ml), it is not necessary to carry out confirmed tests on all the positive tubes.

\(^a\) In the shorter method
If all the five (three) tubes of two or more consecutive dilutions are positive, then the set of tubes should be selected that represents the smallest sample volume for which all the tubes are positive. The confirmed test should be carried out on all these tubes and on all the positive tubes corresponding to subsequent and lower volumes. The following example should help to illustrate this procedure. After a period of 24 hours' incubation, five tubes with 10 ml, five with 1.0 ml, five with 0.1 ml, four with 0.01 ml and one with 0.001 ml gave positive results. Thus the confirmed test should be carried out on the positive tubes initially inoculated with 0.1 ml, 0.01 ml and 0.001 ml of sample.

9. Direct faecal coliform method

If unchlorinated water from small-community water supplies is tested, and only the number of faecal coliforms is of interest, a direct multiple-tube faecal coliform method can be used. This can also be used in developing countries or during field investigations if space, manpower or incubation facilities are limited. The method is based on the normal MPN procedure in which lactose broth is used as a presumptive medium, but the tubes are incubated directly in a water-bath at 44±0.5°C, without prior testing for total coliforms at 35 or 37°C for 24 hours.

The procedure is similar to that described for the examination of polluted water, but uses lactose or MacConkey broth as the presumptive medium (see section 6.1). Prepare 15 tubes of sample and medium, as described in section 6.1 A–E.
A. After gently shaking the tubes to mix the contents, incubate the 15 tubes at 44°C for 24 hours.

B. Observe each tube for the presence of gas and enter the number of positive tubes after 24 hours in the appropriate table.

C. Negative tubes should be reincubated for a further 24-hour period, after which they should be observed for the presence of gas.
D. Confirm the presumptive results after 24 and 48 hours by transferring a loopful of broth to a confirmative broth, and incubating at 44°C for 24 hours.

![Confirmative broth](WHO_85340)

E. The presence of faecal coliforms is confirmed if gas is present in the confirmation broth after 24 hours at 44°C. Determine the MPN from Table 2.

![Confirmation broth and incubation](WHO_85338)

10. Record forms

The analysis of a given sample will provide several results. The form drawn up for recording these results, although it should not be complicated, must be complete. The completed form should contain the data on the sampling, which will also serve to identify the samples, those entered on the sample dispatch form, and data on the bacteriological analysis itself. A suggested comprehensive form is shown in Fig. 3. Once the analysis is completed the laboratory carrying out the work should record the results obtained in a standardized form (protocol); this should follow the
Fig. 3. Suggested comprehensive form for recording results of analyses by the multiple-tube method

<table>
<thead>
<tr>
<th>Sample identification</th>
<th>Sender</th>
<th>Data and time of collection</th>
<th>Date and time of first analysis</th>
<th>Residual free chlorine (mg/litre)</th>
<th>Sample volume inoculated (ml)</th>
<th>No of positive tubes in presumptive test 35 or 37°C</th>
<th>No of positive tubes in confirmed test 35 or 44°C, 37°C, 24 h 48 h</th>
<th>MPN</th>
<th>Total Faecal coliforms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample no.</td>
<td>Community</td>
<td>Sample type</td>
<td>Place</td>
<td>Source</td>
<td>24 hours</td>
<td>48 hours</td>
<td>Total</td>
<td>37°C, 24 h</td>
<td>48 h</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig. 4. Suggested protocol for results of bacteriological analysis

| Community: | Sample No. ...... |
| Sample Site: | |
| Place: | |
| Source: | |
| Sender: | |
| Date of Sampling: / / | Time: |
| Date of Analysis: / / | Time: |

**Results**

| Residual Free Chlorine: | mg/litre |

**Total Coliforms:** / 100 ml

**Faecal Coliforms:** / 100 ml

**Water Bacteriologically:**

GOOD - BAD

*Laboratory Technician*

*Chief (Signed)*
recommendations suggested in Chapter 2. This protocol can be a very simple report, which records the sample identification information together with the result of the analysis and the appropriate classification of the water. An example of such a protocol is given in Fig. 4.
ANNEX 6

MEMBRANE-FILTER METHOD

1. Principle

In contrast to the multiple-tube method, the membrane-filter (MF) method gives a direct count of total coliforms and faecal coliforms present in a given sample of water. The method is based on the filtration of a known volume of water through a membrane filter consisting of a cellulose compound with a uniform pore diameter of 0.45μm; the bacteria are retained on the surface of the membrane filter. When the membrane containing the bacteria is incubated in a sterile container at an appropriate temperature with a selective differential culture medium, characteristic colonies of coliforms and faecal coliforms develop, which can be counted directly. The advantages of the method are described in Chapter 5 (p. 29).

2. Volume of water sample for filtration

Since the filtration area is relatively small, it can only support the growth of a limited number of colonies. The optimum number is between 20 and 80 colonies, with a maximum of 200. If this figure is exceeded, very small atypical colonies or superimposed colonies may develop, or growth inhibition due to overpopulation may result. The choice of the volume of sample to be filtered will depend on the type of water.

As a general rule, the following filtration volumes should be employed:

<table>
<thead>
<tr>
<th>Type of water</th>
<th>Volume of sample to be filtered (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good quality treated water</td>
<td>50–100</td>
</tr>
<tr>
<td>Untreated drinking-water</td>
<td>10–50</td>
</tr>
<tr>
<td>Surface water</td>
<td>1–10</td>
</tr>
</tbody>
</table>

If the origin of the sample is unknown and its probable bacterial content is uncertain, water volumes differing by a factor of ten should be filtered in order to find the appropriate range for the analysis. If the volume to be filtered is less than 10ml, at least 20ml of sterile dilution water should be placed in the funnel prior to the filtration.
3. Equipment

In addition to the basic equipment and glassware used in the MT method (see Annex 5, section 3), the following items are necessary for carrying out the MF technique:

(a) **Water aspirator**, electric vacuum pump or any convenient means of producing a partial vacuum of at least half atmospheric pressure.

(b) **1-litre Erlenmeyer (side-arm) flask** and attached rubber tubing of adequate wall thickness to avoid tubing collapse when the vacuum is applied.

(c) **Filter support**, consisting of a porous base or support for the filter, which can be mounted in the Erlenmeyer flask by means of a rubber stopper, together with an upper container that can be clamped to the porous support. The two parts of the filter support should be wrapped separately in paper and sterilized in the autoclave for at least 15 minutes at 121°C.

(d) **Glass or plastic Petri dishes** measuring 60 x 15 mm (ointment tins of the same size can also be used).

(e) **Membrane filters**, 47-50 mm in diameter, with a pore diameter of 0.45 μm. Singly packed, presterilized membrane filters are very convenient. Unsterilized membrane filters can also be used, however, and these should be wrapped in paper packets in convenient numbers (depending on the number of water samples to be tested); these can then be sterilized in the autoclave and dried by rapid exhaustion of the steam.

(f) **Nutrient absorbent pads**, consisting of filter-paper discs about 1 mm thick, and having the same diameter as the membrane filters.

(g) **Forceps**.

(h) **A magnifying lens** with a magnification of 4 or 5 for examining and counting the colonies on the membrane filters.

4. Culture media and dilution water

Various media can be used for the examination of coliform organisms by the membrane-filtration method. Of these, lactose tergitol agar, lactose TTC, tergitol agar and lauryl sulfate lactose broth may be used for coliform organisms at 35°C or 37°C, and for faecal coliform organisms at 44°C. Endo-type media should only be used for coliform counts at 35°C or 37°C, and MFC broth at 44°C for faecal coliform counts. Although all these media rely on the fermentation of lactose for the detection of presumptive coliform organisms, the characteristic reaction varies with each medium. The characteristic metallic sheen of colonies on Endo-type media depends on the formation of aldehyde.

Although it is possible to prepare the media from the basic ingredients, this may be impractical for a small laboratory. The use of dehydrated media is therefore recommended. The media can be prepared as a broth, and used together with nutrient absorption pads, or as solid agar plates. The broths may be solidified by the addition of 1.2-1.5% agar before boiling.
By way of example, the procedures for preparing small quantities of media are given below for M-Endo MF broth and MFC broth:

(a) **M-Endo MF broth**

(i) Dissolve 2.4 g of dehydrated culture medium in 50 ml of distilled water and add 1 ml of 95% ethyl alcohol.
(ii) Sterilize by heating gently just to the boiling point.

The medium can be stored for up to 4 days in the refrigerator; about 50 ml of medium is sufficient for some 25 tests.

(b) **MFC broth**

(i) Dissolve 1.9 g of the dehydrated medium in 50 ml of distilled water containing 1.0% rosolic acid in 0.2 mol/litre sodium hydroxide solution.
(ii) Heat the medium to boiling point.
(iii) Rapidly remove from the heat and cool to below 45°C.

The prepared medium should not be sterilized by autoclaving; it can be stored for up to 4 days in the refrigerator.

Dilution water should be prepared as described in section 4.2 of Annex 5.

5. Procedures

General procedures are described here; different types of filtration units and equipment exist, however.

5.1 Determination of total coliforms

A. Connect the Erlenmeyer (side-arm) flask to the vacuum source (turned off) and place the porous support in position. If an electric pump is used, it is advisable to put a second flask between the Erlenmeyer and the vacuum source; this second flask acts as a water trap, and thus protects the electric pump.
B. Open a Petri dish and place a pad in it.

C. With a sterile pipette add 2ml of selective broth medium to saturate the pad.

D. Assemble the filtration unit by placing a sterile membrane filter on the porous support, using forceps sterilized by flaming.
E. Place the upper container in position and secure it with the special clamps. (The type of clamping used will depend on the type of equipment.)

F. Pour the volume of sample chosen as optimal, in accordance with the type of water, into the upper container. If the test sample is less than 10 ml, at least 20 ml of sterile dilution water should be added to the top container before filtration (see section 2 of this Annex). Apply the vacuum.

G. After the sample has passed through the filter, disconnect the vacuum and rinse the container with 20–30 ml of sterile dilution water. Repeat the rinsing after all the water from the first rinse has passed through the filter.
H. Take the filtration unit apart and, using the forceps, place the membrane filter in the Petri dish on the pad with the grid side up. Make sure that no air bubbles are trapped between the pad and the filter.

I. Invert the Petri dish for incubation.

J. Incubate at 35°C or 37°C for 18–24 hours with 100% humidity (to ensure this, place a piece of wet cotton wool in the incubator). If ointment containers or plastic dishes with tight-fitting lids are used, humidification is not necessary.
Colonies of coliform bacteria are a medium red or dark red colour, with a greenish gold or metallic surface sheen. This sheen may cover the entire colony, or appear only in the centre of the colony. Colonies of other types should not be counted. The colonies can be counted with the aid of a lens. The number of total coliforms per 100 ml is then given by:

\[
\text{Total coliforms per 100 ml} = \frac{\text{no. of coliform colonies counted}}{\text{no. of ml of sample filtered}} \times 100
\]

5.2 Determination of faecal coliforms

The procedure for faecal coliforms is similar to that used for determining total coliforms. Filter the sample as described, and place the membrane filter on the pad saturated with, for example, MFC medium.

A. Place the dishes in an incubator at 44 ± 0.5°C for 24 hours with 100% humidity. Alternatively, tight-fitting or sealed Petri dishes may be placed in water-proof plastic bags for incubation.

B. Submerge the bags in a water-bath maintained at 44 ± 0.5°C for 24 hours. The plastic bags must be below the surface of the water throughout the incubation period. They can be held down by means of a suitable weight, e.g., a metal rack.
The colonies of faecal coliform bacteria are blue in colour. The non-faecal-coliform colonies are grey or cream coloured. The colonies can be counted with the aid of a magnifying lens and the number of faecal coliforms per 100 ml is then given by:

\[
\text{Faecal coliforms per } 100 \text{ ml} = \frac{\text{no. of faecal coliform colonies counted}}{\text{no. of ml of sample filtered}} \times 100
\]
ANNEX 7

DETERMINATION OF RESIDUAL FREE CHLORINE

Two procedures can be used to determine residual free chlorine; one is based on a commercial visual comparator and the other involves visual inspection and comparison of the colour developed in test tubes. Two different reagents are available for use, N,N-diethylparaphenylenediamine (DPD) and orthotolidine (OT); the latter has the disadvantage of being a carcinogen and, if used at all, must be handled with extreme caution.

Brief details are also given here of a method based on the use of starch and potassium iodide. This method, however, is not specific for residual free chlorine and may therefore give false positive results. Despite this limitation, it has been included because of its widespread use in many countries.

1. Commercial visual comparator technique

1.1 Equipment

Commercial comparators are of two basic types: (i) the disc type, containing a wheel of small coloured glasses; and (ii) the slide type containing liquid standards in glass ampoules. However, both consist of the same components: a box with an eye-piece in front and two cells, the whole arranged so that both cells are in the field of vision of the eye-piece.

One cell, containing a water sample without the reagents, is placed in line with the rotating coloured glasses or the ampoules containing the standards. The water sample containing the reagent is placed in another cell. If free chlorine is present, a colour will develop. The concentration of chlorine is estimated by matching the colours in both cells, as seen through the eye-piece. Each colour of the disc or ampoule corresponds to a certain quantity of chlorine in the water; different calibration discs or ampoules are needed for each of the reagents specified.

1.2 Reagents

As most comparators are intended for use with the manufacturer's reagents, care must be taken to keep a good stock of them. This is a disadvantage, since it involves dependence on the local supplier, and occasionally importation problems can arise. On the other hand, an advantage of the technique is that it is not necessary to prepare solutions of standards, which makes it very easy to carry out.
1.3 Determination of free chlorine

A. Rinse a comparator cell two or three times, and then fill it with the water sample up to the mark on the cell.

B. Place the cell in the cell carrier of the comparator, which is in line with the coloured standards (B).

C. Rinse the second cell and fill it with the same water.
D. Add reagent in the second cell, in accordance with the manufacturer's instructions.

E. Shake the cell (for not more than 3–5 seconds) so as to mix the reagent.

F. Place the cell in the comparator (A).
G. While holding the comparator facing good natural light, rotate the disc until the colour of a standard (B) is the same as that developed by the reagent (A). Immediately (i.e., in less than 20 seconds) read at C the value of free chlorine in mg/litre; cooling the sample to about 1°C is also advantageous (see Chapter 6, p. 33).

2. Test-tube technique

The standard test-tube technique involves the use of Nessler tubes. For field use, however, ordinary test-tubes can be employed. The method is based on visual comparison between the colour developed in a tube to which the reagent has been added and the colour of preprepared standard solutions contained in sealed test tubes.

Since most drinking-waters are chlorinated to give a final residual chlorine concentration of less than 1 mg/litre, the permanent colour standards are prepared only for the range 0.0–1.0 mg/litre. As with the commercial comparator technique, the rapidity of determination (less than 20 seconds) will help to prevent the reagent acting on any combined chlorine present and thus reduce the risk of falsely high free chlorine values. Cooling the sample to about 1°C also minimizes the error from any combined chlorine present (see Chapter 6, p. 33).

Application of the test-tube technique requires that a local or regional laboratory prepare the colour standards and reagents. The necessary equipment, reagents and procedures are described in the relevant literature on analytical methods (see Bibliography).

3. Starch-potassium-iodide method

3.1 Equipment

The following are required:
—100-ml measuring cylinder;
—dropper pipette.

3.2 Reagent

Dissolve 2 g of soluble starch in 100 ml of distilled water. Boil the solution and allow it to cool to room temperature. And 8 g of potassium iodide and
agitate the mixture until it is completely dissolved. Store the solution in a brown glass bottle. If 2 or 3 drops of chloroform (or formaldehyde) are added, the solution will remain stable for 2–3 weeks.

3.3 Determination of residual chlorine

A. Add 5–6 drops of the starch–iodide solution to 100 ml of water sample in a measuring cylinder.

B. Mix thoroughly.

The residual chlorine content of the water sample is found from the colour produced, as follows:

<table>
<thead>
<tr>
<th>Colour</th>
<th>Residual chlorine (mg/litre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No colour</td>
<td>0.0</td>
</tr>
<tr>
<td>Light blue</td>
<td>0.1–0.3</td>
</tr>
<tr>
<td>Dark blue</td>
<td>&gt;0.3</td>
</tr>
</tbody>
</table>
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